THE ECOLOGY AND DISTRIBUTION OF ROCK-BORING PELECYPODS OFF DEL MONTE BEACH, MONTEREY, CALIFORNIA

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THESIS

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by

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ABSTRACT

Divers using SCUBA gear gathered and identified rock-boring pelecypods found in the subtidal outcrops of Monterey silicious shale off Del Monte Beach, Monterey, California. Underwater photographs were taken of all the recognizable species present.

A species distribution and mapping survey was made along two transects, one of which would be subjected to radical ecological change after isolation from the open sea by a proposed breakwater project.

Most species found are common to both transects. Their distribution is variable and depends to a great extent on the character of the substrate, which varies from soft, carbonate-rich mudstone to chert. However, within this framework of distribution dependent on substrate, there are inconsistencies which remain unresolved.

TABLE OF CONTENTS

LIST OF FIGURES

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I. INTRODUCTION

A. HARBOR DEVELOPMENT PLANS

1. Reasons for Development

For several years there have been plans to construct two additional breakwaters so as to enlarge the protected harbor area at Monterey, California. Although the size of the fishing fleet has declined since the disappearance of the sardine in the late 1940's, recreational boating and sport fishing craft have filled the harbor, resulting in long waiting lists of people wishing to rent slip space at Monterey. Also, the lack of a harbor of refuge along the coast from San Francisco to Santa Barbara represents a hazard to mariners. It is in response to these needs that the present breakwater project has been planned.

2. Plans for Construction and Use

Figure 1 shows the present layout of Monterey Harbor. The present structures provide adequate protection to larger boats anchored in the outer harbor and to small craft in the marina. Figure 2 shows the Army Corps of Engineers plan which is still awaiting funding. The new breakwaters of granite block construction will form a protected basin several times the size of the existing harbor. The construction of the breakwaters will be the first phase of the plan with the addition of the earth and rock filled moles anticipated several years later. The central mole will be the heart of the project. From

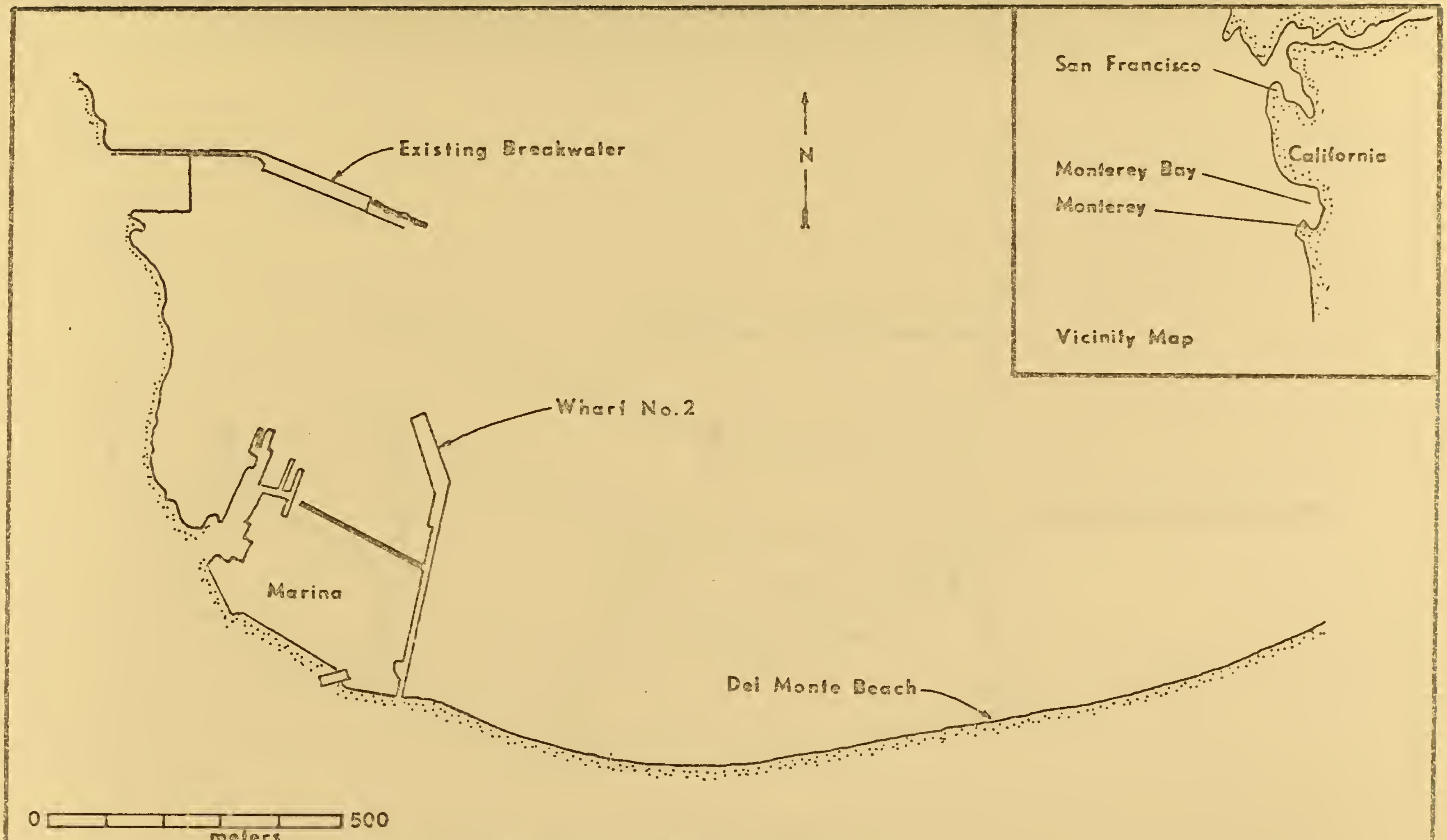

Figure 1. Present Harbor Area
Monterey, California

(from Minter, 1971)

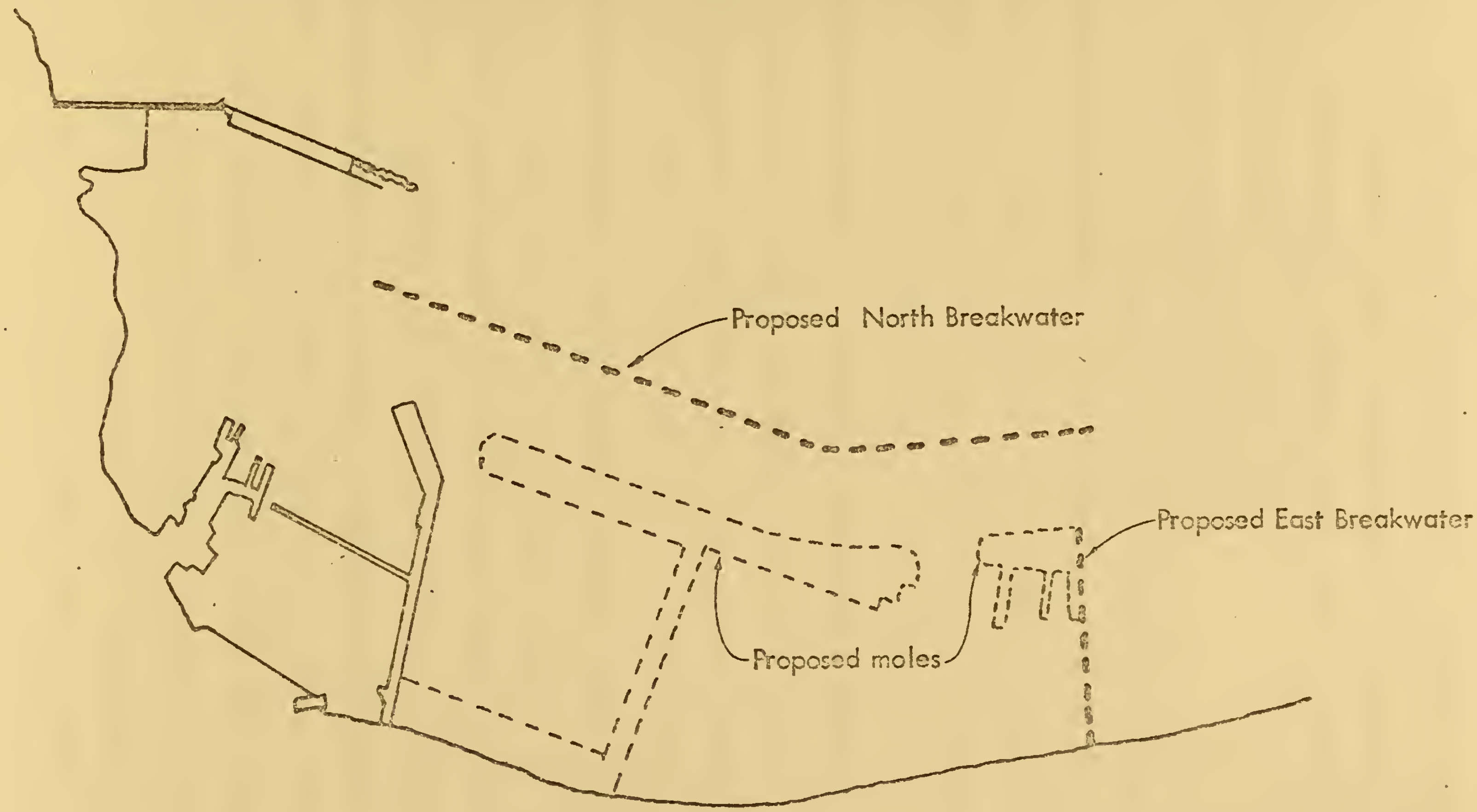

Figure 2. Proposed breakwater and mole structures

(from Minter,1971)

it, numerous floating docks will provide access to the 1,700 slips proposed in the plan. In addition, parking, hotel, and restaurant facilities are planned for the central mole. The smaller mole at the end of the eastern breakwater is designed to provide pier space for oceanographic research vessels.

B. MONTEREY BREAKWATER STUDY

In order to determine the ecological effects of the proposed breakwaters, a comprehensive study under the direction of Dr. Eugene C. Haderlie is being conducted by students and faculty of the Department of Oceanography at the Naval Postgraduate School. The purpose of the Monterey Breakwater Study is to establish ecological base lines in this relatively undisturbed area so as to have a basis for comparison for post-construction studies (Haderlie,1971).

The study is structured about a set of four transect lines upon which 15 individual stations have been surveyed (Fig. 3). These stations were charted so as to include all types of bottom substrate with water depths ranging from 2 to 15 m. A grid of 12 navigation poles, in conjunction with the markers delineating the transects, facilitates location of the stations to within a few square meters (Fig. 4). On applicable stations, sediment grain size and sediment depth are monitored on a periodic basis. Vertical plankton hauls are made regularly. Parallel to the transects, dredges and balloon trawls are used to collect bottom dwellers and demersal fishes. A Smith-MacIntyre benthic grab is being

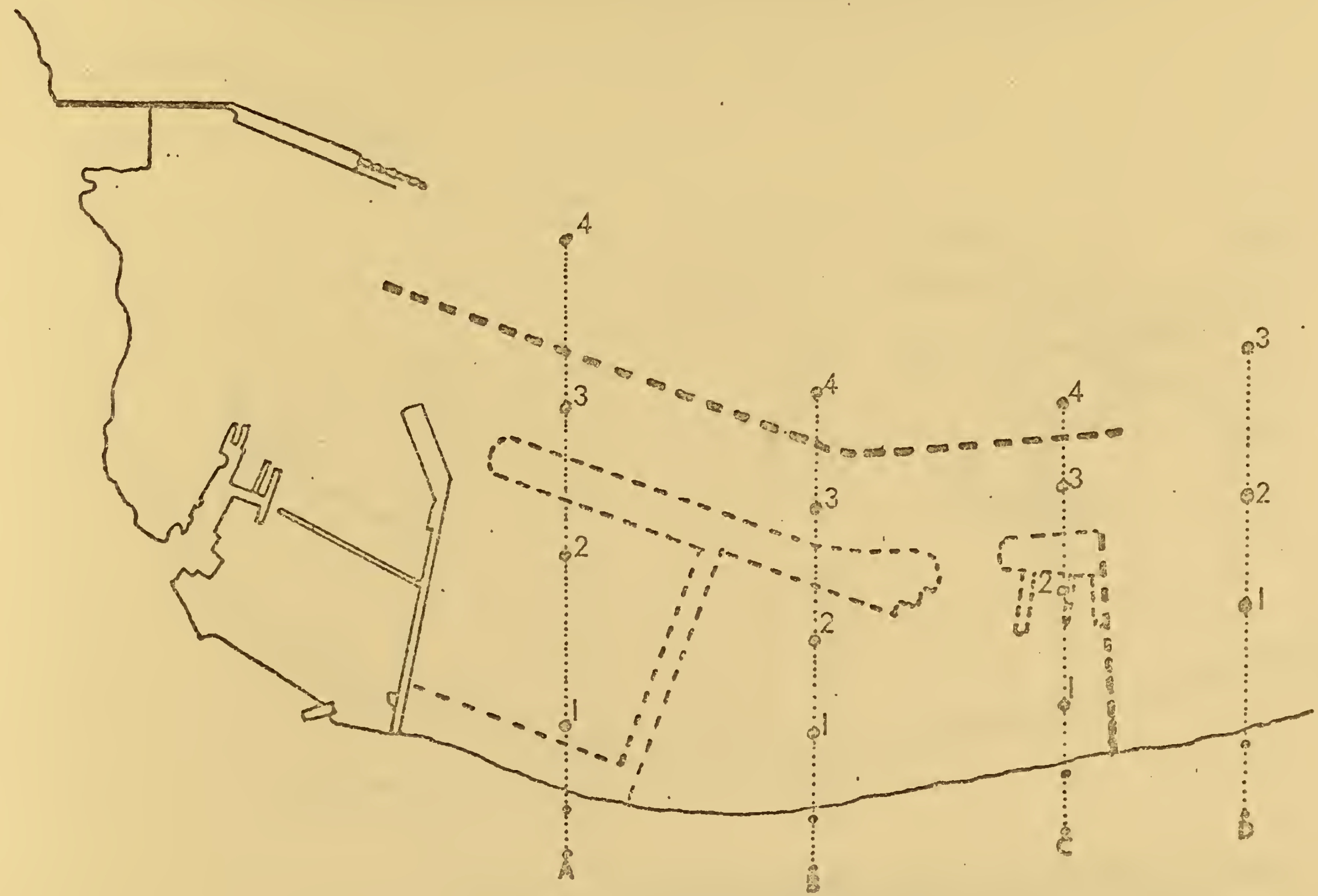

Figure 3. Location of transect lines

(from Minter, 1971)

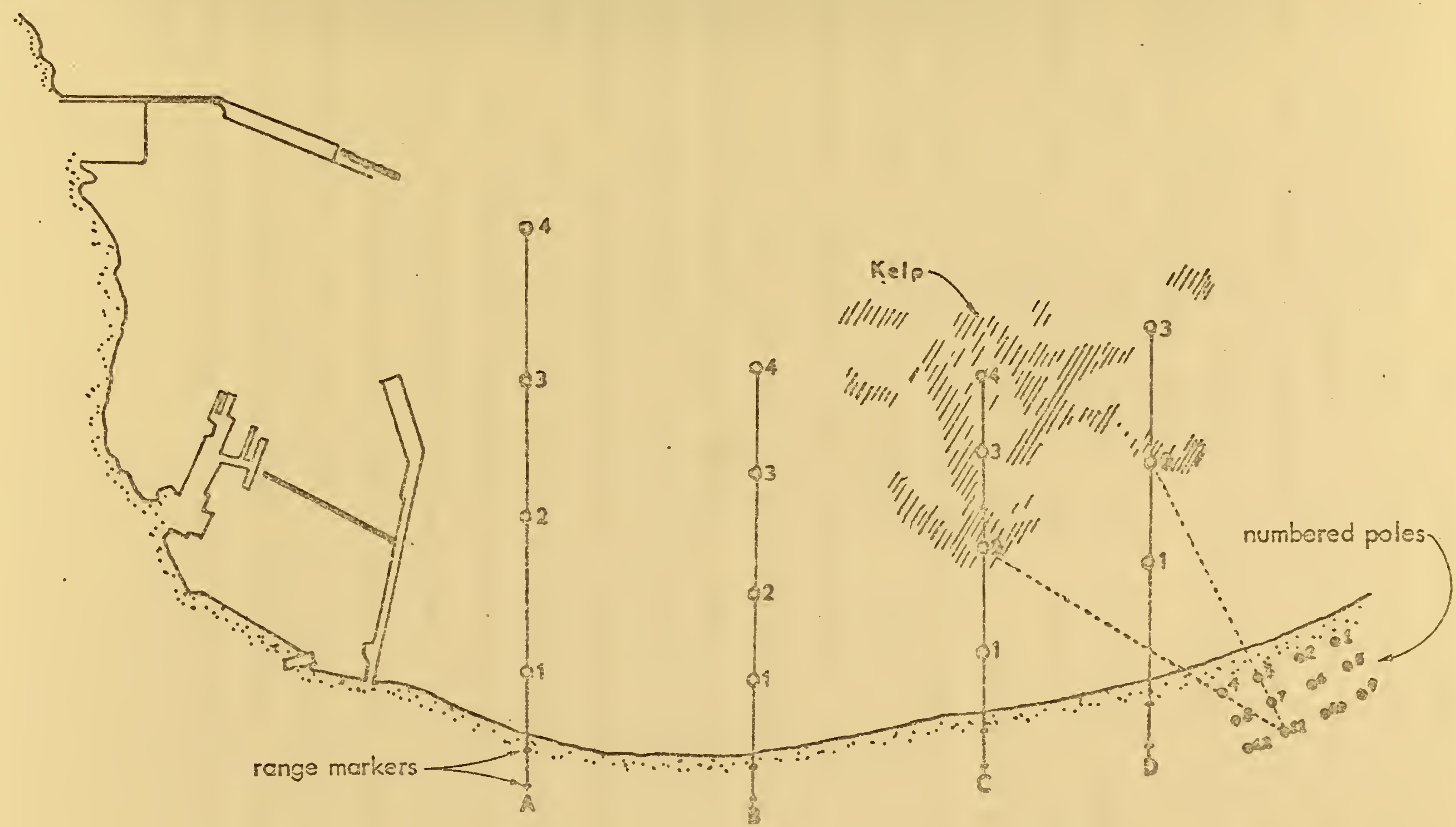

Figure 4. Triangulation system used in transect station location. Location of Del Monte Beach kelp beds is also shown.

(from Minter, 1971)

used to sample the infaunal assemblage (Haderlie,1971). Divers have measured and outlined with polypropylene line two stations with exposed shale bottoms. These two stations have been intensively studied with divers gathering, identifying, mapping and counting the specimens of the some 160 species found (Minter,1971).

Wave data, tide records, and continuous traces of temperature and salinity are also available as additional inputs to the study. The ecological studies of the pilings of Wharf No. 2, done over the past few years by the students of the Naval Postgraduate School, and the extensive studies by Haderlie (1968,1969,1970) of the local fouling and wood boring fauna will supplement the data gathered in the Monterey Breakwater Study itself. Thus, prior to the start of construction of additional harbor facilities, an extensive and reasonably accurate data base will be available to which post-construction studies can be compared.

This author has completed a small portion of the overall study and the results are reported in this thesis. Work was divided into two major areas; first, detection, identification, and recognition of rock-boring pelecypods and second, mapping and *in situ* observation. Fifty-three SCUBA dives were made by this author to accomplish the objectives.

II. NATURE OF THE PROBLEM

A. OBJECTIVE

As a part of the Monterey Breakwater Study the objective of this work was to examine and document the distribution of rock-boring pelecypods in the area to be affected by the construction of additional wave barriers in southern Monterey Bay. The problem of species recognition had to be solved before meaningful data could be taken.

B. SPECIES DETERMINATION AND RECOGNITION

Species determination for most bivalves is a relatively easy and accurate process. Valve morphology is the usual key to identification while only infrequently are the soft parts of the animal used for taxonomic purposes. For common bivalves of the Pacific Coast of North America, the book by Keen (1963) is a useful morphological guide.

The identification and *in situ* recognition problems with rock borers are varied, some apparent, some more subtle. The obvious problem is that the siphonal tips are the only parts of the animal presented to view. The not so apparent problem arises from the paradox that although the pholads are able to bore into reasonably durable rock, the valves of some species are as fragile as egg shells. In addition, the animal may have bored to a depth of more than 2 ft. Extracting an undamaged, living specimen from its tapering conical burrow in 2 ft of rock is not a simple task.

However, the identification and _in situ_ recognition problems are not insoluble. In Turner's (1954,1955) excellent works on the family Pholadidae, there is for each species some mention of the appearance of the posterior end of the siphons. The siphon tips vary from very distinctive (_Chaceia_, _Parapholas_) to relatively indistinct (_Penitella_ sp.). Siphon size and _in situ_ recognition accuracy are directly related. The shells of the smaller pholads, although generally more fragile, are only a matter of inches beneath the surface of the rock and are relatively easy to extract. Once the complete shell is available, identification is simplified. Emphasis should be placed on the complete shell, which includes the two main valves and the accessory parts. The pholads, usually upon reaching the end of the boring phase of their life cycle, form these accessory parts as covering and protection to muscles and visceral areas that were exposed or exterior to the valves during boring. Although rarely is more than one species present in a given locality for each genus, where two or more species of the same genus are found together (as is the case at Monterey with the genus Penitella) the accessory parts are essential to correct species identification.

C. UNDERWATER MAPPING

The underwater mapping was done along the C and D transects (Fig. 4). Well marked polypropylene line was

laid down along a transect and anchored. Divers then proceeded to observe and record the species and relative abundance of the rock borers and the character of the substrate. In areas of exposed rock, samples of the shale were brought back to the laboratory to determine their relative hardness. In sandy areas sand depth measurements were made, especially if pholads were boring the rock beneath.

In observing and mapping the pholads, detection was the main problem. The siphons of all the local rock borers except _Chaceia_, _Parapholas_, _Zirfaea_, and _Barnea_ are on the order of a few millimeters in diameter when in the full open position. They protrude very little from the substrate and may even be several millimeters below the surface even when open and feeding. When alarmed in any way the siphons first close, and if further alarm stimuli are received they can be withdrawn well into the burrow, if not all the way within the valves. Common sources of alarm are attack by crabs or fish, strong wave surge and rapid pressure fluctuations caused by the bubble collapse of a diver's exhaled air. The bubble collapse problem is most severe with the species _Barnea subtruncata_. However, the most persistent problem is wave surge, which not only causes reduced visibility but also causes grains of sand to roll into or shower upon the siphons causing them to close or even retract. Moderate surge in sandy areas greatly reduces the number of species and specimens seen.

III. EQUIPMENT AND METHODS

A. CLIPBOARD AND RECORDING SLATE

As in a previous study (Minter, 1971) an inexpensive fiberboard clipboard was used to which a soft lead pencil was attached by a nylon line. As suggested by Minter, white bakelite, 0.04 inches thick, cut to standard size, was used as a recording slate. In addition to the strong wide clip, several elastic rubber bands were used to secure the bakelite sheet to the clipboard after one such sheet was lost in the surf zone.

B. PROBES

Two probes were used in this study. Constructed of 3/16- and 3/8-inch diameter drill rod with welded T handles, they were scribed every centimeter, double scribed every 10 cm, and marked with blue paint every 20 cm. Each was 90 cm in length and had a tapered pointed tip. The smaller diameter probe was used for determining bore depths and sand depths where the cover was not too thick. The larger probe was more rigid and was used to determine the depth of thick sand cover. Whenever sand depths were recorded, multiple measurements were taken so as to reduce the possibility of erroneous measurement resulting from the probe entering an unoccupied pholad bore.

C. DIGGING TOOLS

For digging out borers or obtaining rock samples a variety of hammers and chisels were tried. For extracting deep-boring pholads, a hand-held pneumatic hammer, adapted by Anthony Weaver of Hopkins Marine Station, Pacific Grove, California, for use with a conventional SCUBA tank, was fitted with a standard 1-inch steel-cutting chisel modified with an extra long shaft. For gathering smaller specimens a 1-inch wide stainless steel chisel and a short handled mallet were used with good success. For carefully chipping away the rock surrounding a pholad in its burrow, a sharp tool-steel drill punch was used to localize the force of the hammer's stroke. Frequently this was unnecessary as the piece of weakened shale would split right through the pholad burrow.

D. REFERENCE LINE

1. Description

The piece of equipment at the heart of the mapping survey was a carefully marked length of 1/4-inch yellow polypropylene line. It was marked every meter with a wrapping of blue vinyl tape and every 5 m with a 1-inch wide strip of white nylon. These 8-inch white nylon "flags" were marked with a permanent marker and attached to the line with short pieces of soft stainless wire.

2. Installation

a. D Transect

The 320 m line was put in place using a 13-ft skiff and outboard motor. It was first placed along D

transect so that the shoreward end would be at the first exposed shale, 80 m short of station D2 (Fig. 3). It was anchored with 100 lb of lead at the zero mark where the wave surge was greatest; 50-lb lead weights anchored the middle and far end of the line. After the shoreward anchoring weights were attached to the line and dropped in place, the line was unreeled along the transect. After a slight tension was put in to straighten the line, the far end anchor was dropped. Divers then attached 2-lb weights every 25 m and attached the center anchoring ball at the 160-m mark. After the mapping, photography, and observation were completed along D transect, the weights were removed and the line was checked for wear.

b. C Transect

A different procedure was used to lay the line along C transect. Whereas D transect is relatively free of the giant kelp Macrocystis pyrifera, C transect has a heavy growth of it (Fig. 4). The line was rerolled on a metal reel and unreeled along the bottom by divers using a compass bearing and frequent checks at the surface for navigation. With the 100-m mark just east of station C2 (Fig. 3), the line was anchored in the same manner as along D transect, except that the weights were attached as the line was unreeled.

This method of putting the line in place was less accurate and, unlike the case for D transect, it could not be straightened due to the columns of kelp

stipes. The line has been left in place on C transect, attached to the lead weights with stainless steel shackles.

E. PHOTOGRAPHY

A Nikonos 35-mm camera in conjunction with a Subsea Mark 150 battery powered strobe unit was used for all underwater photographs. In the often murky, turbid water, results were generally poor except for properly illuminated close-up pictures. The use of the Nikonos is quite flexible for close-ups. Although the basic camera and lens can focus only into a range of 2.75 ft, by using the Nikonos extension tubes various image sizes can be achieved. The largest image size is achieved when using the 1-to-1 extension tube where an object 25 mm in size is reproduced on 25 mm of the negative. Whereas total width of field is only as wide as the negative (35 mm), very small objects can be photographed with good clarity and resolution. The extension tubes are not without one disadvantage; changing extension tubes requires opening up the camera. Thus, selection of an extension tube must be made when the dive is planned, and the decision has to be based on what the diver expects to photograph, not what he actually finds to photograph. Most of the photographs in Appendix B were taken using the 3-to-1 extension tube (35 mm of negative represents 105 mm of subject when in proper focus.).

Most photographs were taken using High Speed Ektachrome color reversal film (ASA 160, 23 DIN) made into slides. Best results were obtained using a strobe setting

of 100 w-sec at 12 inches and camera settings of f 22, 1/60 sec and 2.75 ft when using the 3-to-1 extension. Some longer range pictures were taken when visibility permitted. Good results came from settings of 150 w-sec for the strobe and 1/60 sec, varying the f stop for different distances (3 ft, f 11; 4 ft, f 8; 5 ft, f 5.6). All slides remain on file with the Department of Oceanography at the Naval Postgraduate School.

IV. PRESENTATION OF DATA

A. GENERAL

The raw data collected along C and D transects during this study are presented in Appendix A as individual sets of strip charts showing the character of the substrate and the major topographic features in addition to a symbolic plot of the distribution of the rock-boring pelecypods.

B. ACCURACY

1. Errors in Species Identification

Many factors, such as valve and accessory part morphology, visible siphon characteristics, and bore depth, were used in identification of the rock borers. This does not, however, preclude the possibility of misidentification. *In situ* identification accuracy should be considered very high for specimens recognized as *Chaceia*, *Parapholas*, or *Barnea* as their siphons are very distinctive. In addition, the siphons of *Zirfaea* are distinctive when the size factor is included. Conceivably, young *Zirfaea* could be misidentified as mature *Penitella* sp. as their *in situ* recognition characteristics are similar. Hopefully, errors of misidentification have been kept to a minimum.

2. Errors Due to Poor Visibility

a. General

Visibility in the area under study was generally poor. This author's estimate of average

visibility of 6 to 8 ft is based on one year's diving experience in the study area. Reduced visibility was a product of several superimposed factors.

b. Sewage

The City of Monterey sewage outfall line runs approximately parallel to D transect and empties into the Bay at a point about 600 m northeast of station D2. A large surface slick was usually visible from the bluff behind the beach or from the air. Under the influence of the prevailing north winds and weak local currents, the sewage effluent was spread back along the beach and to the west (Trumbauer,1966). It contributed materially to the poor visibility.

c. Plankton Blooms

Although the nutrients added by the sewage effluent may contribute to a higher sustained plankton level in the area, the effects of the spring and fall plankton blooms were still noticeable. Divers reported during the middle two weeks of October 1971 that luminescence was so intense throughout the water column that visibility was reduced to zero as long as the diver was moving through the water. Although visibility was 10 to 15 ft when the diver was still, as he moved, the turbulence around his faceplate triggered the bioluminescent reaction in the planktonic organisms (presumably Noctiluca). A motionless diver could observe a moving diver enveloped in a brilliant blue cloud and seemingly exhaling blue bubbles.

The bottom turbulence generated by long period swell also caused the organisms to luminesce, blanketing the substrate with a blue fog. Benthic observation was impossible as each wave of turbulence approached and passed.

d. Wave Turbulence

In addition to the special case of poor bottom visibility due to wave turbulence described above, long period swell generates its own brand of poor visibility. The turbulent water motion caused by the interaction of the horizontal surge and the rough bottom puts all the finer sand, silt and algal detritus into suspension. Another wave-generated visibility problem is that the diver is being moved back and forth with the surge and remaining stationary relative to the bottom while observing benthic organisms varies from annoying to impossible.

e. Sun Angle

The foregoing reasons coupled with a low sun angle during the winter months all contribute to the production of error due to poor visibility.

3. Lack of Detail

Time limitations, coupled with less than adventageous environmental factors, have precluded a more detailed distributional survey of the rock-boring pelecypods in the study area. Further researchers should be wary of attempts at greater detail with respect to *in situ* benthic surveys of organisms that are difficult to both detect and recognize.

V. RESULTS

A. SPECIES DISTRIBUTION AND RECOGNITION CHARACTERISTICS

1. *Parapholas californica*

Parapholas is the most widely distributed and most obvious rock borer in the study area. It is easily distinguished by its cylindrical, flat-tipped united siphons. The incurrent siphon is three times the diameter of the excurrent siphon and is surrounded by numerous branched cirri which give it a lace-like appearance. The excurrent siphon protrudes a few millimeters above the flat disk of the siphons and is nearly smooth. A second ring of short cirri surround the combined siphons making it look like a coin with a reeded edge. Color varies from a uniform dark red-brown to pure white. Turner (1955) states that *Parapholas* is found to depths of 30 ft, yet this author has found large colonies of animals at depths of 60 ft. These deepest specimens were found in soft shale at D-306 (Fig. 36) at the base of the outcrop, and nearly the entire colony was pure white. Since other white specimens are found among pigmented ones throughout the area, conclusions should not be drawn concerning pigmentation versus available light.

Parapholas is found boring into the soft shales and its bore is rarely more than 11 inches deep. Since the soft shale erodes rather rapidly, the mature animal

forms a calcareous tube or "chimney" which lines the walls of its burrow (Fig. 45,48). This tube, which thickens with age, stabilizes the shale immediately surrounding the burrow. As the shale later erodes, the cement-like chimney, protruding 1 to 2 inches above the eroding surface of the shale, provides a protective housing into which the animal can withdraw. Parapholas are able to live normally with a sand cover of up to 6 inches. It appears that the siphons are unable to extend more than 6 inches above the top of the bore, although with a thicker sand cover it cannot be assumed that the animal is unable to feed and respire using percolation water in the sand (Fig. 37-49).

2. Chaceia ovoidea

One of the largest pholads, this animal according to Turner's description can extend to a length of more than 3 ft. The siphons are joined except for the posterior 2 inches. When open, the excurrent siphon has the shape of the bell of a musical horn and the incurrent siphon looks like a short length of pipe (Fig. 65,67). Both are usually a uniform deep mahogany red with a white interior. Although there were few dense concentrations of Chaceia along the transects, the area between the transects has many concentrations, mostly along ledges. This author noted that Chaceia appear to be light sensitive. When the beam of a standard underwater light is aimed at a specimen with it siphons open, the animal will often close its siphons and may even withdraw into its burrow.

Although there are many _Chaceia_ boring vertically on flat shale, there are many more boring horizontally into the soft shale below ledges. Many of the ledges in the area, especially the ledges in the very rough area northwest of station D2, appear to have been undercut by _Chaceia_. Many horizontal bores in that area that were probably 2 ft long when the active animal stopped boring are now only 6 to 10 inches long. The large volume of the siphons no longer fits comfortably within the bore and, when unalarmed, up to 4 inches of warty, wrinkled siphon is exposed and dangles from the bore. To this author it appears that _Chaceia_ bores horizontally, either seeking a darkened habitat under ledges or because, in the layered substrate of hard and soft rock, the animal can bore within a layer to full adult size, whereas vertical boring might be stopped short of full size by a hard layer of rock. This supposition is supported by limited data on bore depths of 19 animals which appeared of similar size to the diver. The average bore depth of the animals boring horizontally was 22 inches while that of those boring vertically was 15 inches.

Surprisingly few _Chaceia_ were observed living with a cover of sand. This probably occurs, not because sand has any effect on the living animal, but because the settling preference of the species keeps it out of areas where periodic sanding occurs (Fig. 59-68).

3. *Zirfaea pilsbryi*

Another of the large pholads, *Zirfaea* can bore to a depth of more than 2 ft. Also found in abundance in the tidal mud flats of Elkhorn Slough 14 miles to the north, this vertical borer is limited in the study area to boring in the softest shale and mudstone. More than half of the hundreds of specimens observed were covered with up to 12 inches of sand. The average maximum bore depth as measured from the surface of the rock was 19 inches, although this figure is based on only eight large animals.

The animal will not tolerate sand showers and will withdraw its siphons with even moderate surge. The first time divers mapped D transect, no *Zirfaea* were seen as turbulence was moderate. On later occasions during calm conditions, hundreds were seen along D, although no dense colonies were found as are common for *Parapholas* and *Chaceia*. A density on the order of five *Zirfaea* per m^2 is an average maximum. During calm wave conditions this author, while examining the cirri on the siphon of one animal, observed a small circle of sand start to shift and boil. After about 4 sec the siphons of another *Zirfaea* rapidly emerged, stopping about 1 inch above the surface of the sand. It appeared as though the animal was ejecting water so as to loosen and unconsolidate the sand and facilitate the upthrust of its siphons. The cream-colored siphons marked with reticulations of dark

red-brown are easily missed as they blend well with the sand (Fig. 49-58).

4. Barnea subtruncata

Barnea is a somewhat smaller-valved pholad but a large adult can extend its siphons 2 ft. The siphons are a mottled dark red-brown grading to white at the very tip. The distinctive in situ recognition feature of Barnea is a crown of ten reddish unbranched papillae surrounding the incurrent siphon. Specimens were observed in exposed shale and in areas of 6 to 8 inches of sand cover. No specimens were observed along D transect where wave surge is generally greater. As mentioned earlier, Barnea is particularly sensitive to high frequency pressure changes. The bubble collapse problem may be in part responsible for the fact that only 11 specimens were sighted. Little can be said about distribution except that the species is not abundant in the area (Fig. 69).

5. Nettastomella rostrata

This pholad is too small to be detected by a diver as the siphon tips are on the order of 1 or 2 mm in diameter. The distinctively sculptured valves with characteristic calcareous siphonoplax of two dead specimens were found while gathering rock samples. Nothing can be said about distribution except that the species is present in the study area and is probably rare (Fig. 77).

6. Penitella conradi

This species is fairly common in the study area but its siphons are too small to be detected by divers.

The mature animal adds a chitinous sheath, the siphonoplax, to the posterior edge of the valves, and the siphons do not extend out of these short protective flaps. The distinguishing characteristic is the small accessory part, the mesoplax, which is pointed anteriorly, truncate posteriorly, and lacks lateral wings (Turner,1955). Little can be said about its distribution except that it is not rare and has been found in rocks from both transects (Fig. 72).

7. *Penitella gabbi*

This species is also fairly common in the study area. Although the siphons are visible, they are difficult to identify *in situ*. When removed from the shale, *P. gabbi* is easily identified by the round pustules that cover the exterior of the combined siphons. Also, the mesoplax is distinctive, being pointed anteriorly, rounded posteriorly, and having broad lateral wings. Like *P. conradi*, it is found along both transects in water less than 40 ft deep (Fig. 74,76).

8. *Penitella penita*

This species, reputed to be the most common member of the family Pholadidae along the west coast of North America, is not abundant in the study area. Although isolated valves of dead specimens were found in rock samples, no living specimen was taken. The animal does exist in the study area with unknown distribution (Fig. 75).

9. *Lithophaga plumula*

This pelecypod is not a member of the family Pholadidae, nor is it a true borer, as boring implies rotation of some type of tool about an axis to cut or wear away the medium being bored (Nair,1968). Because of its extremely fragile shell, *Lithophaga* has adapted to using chemical means to hollow out a protective burrow. Formerly thought to secrete a strongly acidic polysaccharide which reacted with carbonates, it has been shown that the secretion by *Lithophaga* is a nearly neutral mucoprotein which complexes with calcium (Jaccarini and Bannister, 1968).

Lithophaga is very abundant throughout the study area and can be distinguished *in situ* by bone-white siphons with several flap-like appendages.

10. *Botula falcata*

This mytilid is thought by some authorities to be only a nestler. However, this author feels that *Botula* must be able to enlarge an existing pholad bore to a great extent. Of the hundreds of specimens dug out of the shale, most filled the burrow rather tightly. Some specimens fit exactly and tightly in the shale while still retaining the valve morphology distinctive of the species. Although there is evidence of wear at the beaks, the tight and exact fit with slightly crescent-shaped valves indicates possible chemical activity. It must be pointed out that these suppositions are based

on _in situ_ observation, not on scientifically documented fact.

Botula is very abundant in the study area and is found with _Lithophaga_ in rock containing carbonates (Fig. 70,71).

11. _Nestlers_

Kellia laperousi, _Sphenia pholadidea_, and _Hiatella arctica_ are common nestlers occupying pholad bores after the deaths of the original inhabitants (Fig. 73).

B. SUBSTRATE

1. Background

a. Monterey Formation

A knowledge of the submarine geology of the study area provides the key to understanding the inhomogeneous distribution of the borers.

The subject area is the only shallow water outcrop within Monterey Bay of the Miocene marine unit known as the Monterey Formation. Although the Monterey Formation underlies most of Monterey Bay south of the Monterey Submarine Canyon, it is covered in most places with several hundred feet of more recent assorted sands and gravels. The Miocene rock is a resistant, brown, silicious mudstone composed mainly of diatomite and diatomaceous shale, interbedded with beds of opaline chert (Greene,1970).

Structurally, the study area represents the most complex geology of the southern Monterey Bay area. The contact between the Miocene Monterey silicious shale on the east and the Cretaceous Santa Lucia granodiorite on the west lies parallel to and immediately east of Wharf No. 2. In a narrow band east of the contact, seismic reflection profiling shows that the Monterey Formation is complexly faulted and folded with synclines and anticlines generally plunging northwest. Away from the contact the Monterey Formation is essentially homoclinal and contains a layer which, based on its seismic

reflection, Greene (1970) believed to be chert. This chert layer lies about 300 ft below the estimated top of the Miocene strata.

b. Tularcitos Fault

Approaching Monterey from the southeast, the Tularcitos Fault becomes discontinuous and difficult to chart. Probably still active today, the Tularcitos exhibits essentially vertical movement with the eastern block down dropped. The conclusion to be made is that the folded and deformed condition of the subtidal outcrops of the Monterey Formation is associated with the Tularcitos Fault, the Tularcitos Fracture Zone offshore, and the contact between the granodiorite and the marine strata (Greene,1970).

2. Observations

Although the contact between the shale and the granodiorite is covered with sand, shale outcrops are exposed midway between transects A and B. Even though most of the shale west of B transect is covered with sand, the flat shale areas that are exposed are being bored by all the species that are found further to the east. This is significant because these areas are alternately covered and swept free of sand, probably depending on the variation of the deep water wave direction from one Pacific storm to the next. Evidently even the small borers are able to either get their siphons up through the sand if it is thin or exist at a probably reduced

metabolic level using percolation water if the sand cover becomes thick.

The most rugged area topographically lies between transects C and D. Most of the area is characterized by hummocks and ledges roughly parallel to the trend of the Tularcitos Fracture Zone. Some of these ledges are contiguous features several hundred meters long. Many of the ledges have been undercut by rock-boring pelecypods and assorted crevice dwellers, such as sipunculid and polychatae worms.

Rock samples were gathered from along C and D transects and from many locations between them. The rocks were not tested chemically except that the dilute hydrochloric acid test was used to detect the presence of carbonates. Time limitations prevented more sophisticated relative hardness tests as were done by Evans (1966b). However, an attempt was made to determine hardness using a Rockwell hardness testing machine, normally used to test metals. All samples tested were too brittle and shattered under load. However, scratch testing provided a rough idea of the range of hardness exhibited by the different samples.

Internally, all the samples, as though overstressed, appear cracked and shattered. Although of non-crystaline structure, they often cleave with planar or nearly planar surfaces orthogonal to the bedding plane.

By examining the seismic reflection profiles

upon which Greene (1970) based his report, it appears that the layer of chert 300 ft below the top of the Miocene strata should surface within the study area. Probably the most significant geological observation of this study is that chert does exist in the subtidal Miocene outcrops. However, in the closest exposed subaerial Monterey shale, chert is not found. In fact, Dr. Robert S. Andrews of the Naval Postgraduate School states that, to his knowledge, subaerially-exposed chert is rare in the Monterey area.

Rock samples other than the chert vary from soft mudstone containing abundant carbonates to gray and black silicious shales of varying hardness. The bedding in the subtidal outcrops is essentially planar, and the thickness of individual layers varies from a centimeter or less to a meter or more with the layers of hard rock tending to be less than 20 cm thick.

C. DISTRIBUTION DEPENDENCE ON SUBSTRATE

With a knowledge that layers of chert and other hard silicious rock are found in the study area, most of the borer distributional inhomogeneities can be easily explained. All the various species easily bore the carbonate-rich mudstones. These soft mudstones only rarely exhibit an encrustation of coralline algae or sponges, indicating that the rock is eroding at a rapid rate, making encrustations unstable. Although the large holdfast of _Macrocystis pyrifera_ is able to attach to

the softer rock, other sessile algae are found anchored only to more durable rock.

The mechanical borers are able to attack the softer silicious shales. As the shale becomes harder the pholads become stunted, thick-valved, and misshapen. Finally there are the hardest shales and the layered chert in which the borers are unsuccessful. These hard rocks are usually encrusted with corallines and sponges.

There are a few areas, however, such as C 225-249 (Fig. 17,18), where the reason for the absence of borers is not apparent. The flat rock is not heavily encrusted, and samples indicate that it is relatively soft and contains some carbonates. Samples of it appear essentially similar to samples taken from adjacent areas presently being bored. The factors which, in general, explain the borer distribution are inadequate to elucidate these anomalies.

D. OTHER BIOLOGICAL OBSERVATIONS

1. Sea Mouse

While investigating the unfamiliar siphons of the cockle *Clinocardium nauttalli*, the author unearthed a sea mouse from under 4 inches of sand. This polychatae worm, *Aphrodita aculeata*, was approximately 4 inches long, 1 inch wide, and 1/2 inch thick. For locomotion it was equipped with 20 to 30 sets of parapodia, each parapod sporting 4 to 6 retractable, 1/2-inch, black setae. Protecting its dorsal surface were two rows of brass-colored spines.

2. Abalones

Minter (1971) states that as a result of sea otter predation the population of red abalone in the Del Monte kelp bed has been annihilated. Although none exist in unprotected areas, this author has sighted more than a hundred mature specimens living deep in caves too narrow for otters to enter. Many of the narrow caves appear to have been formed by pholads boring out the soft rock from between layers of rock too hard for borers to attack. In addition to the red abalone (*Haliotis rufecens*), specimens of the pink (*H. corrugata*), black (*H. cracherodii*), and pinto (*H. kamtschatkana*) abalones were examined and returned to their habitat.

3. Sea Hares

The largest of the sea slugs found in California waters, *Tethys californica*, commonly called the sea hare, was rarely seen by divers in the study area. Yet during the first week of April 1972 divers observed literally hundreds of these foot-long gastropods in the vicinity of C transect. On subsequent dives, April 10 and 11, only a few were seen. Since that time they have been seen only rarely. Although it is thought that they come together in large numbers to breed (Johnson and Snook, 1927), where they came from and why they came to that one site are unknowns.

VI. DISCUSSION

A. CONCLUSIONS ABOUT DISTRIBUTION

The variation of hardness and amount of carbonates of the Miocene marine strata known as Monterey shale is the main factor underlying the inhomogeneous distribution of rock-boring pelecypods in the study area.

B. ECOLOGICAL IMPACT

1. General

The general ecological impact of the proposed breakwaters at Monterey, California, has been treated by Haderlie (1971) and Minter (1971). It is expected that the population of rock borers will be affected.

2. Impact on Borers

a. Salinity Fluctuations

Many of the species of rock borers live in the low intertidal zone in areas where an appropriate substrate is available. The salinity variations are greater there than are those expected within the proposed harbor. The probable range of seasonal salinity variations should have little effect on the boring population.

b. Temperature Variation

For the same reasons as above, temperature variation is not likely to affect the borers.

c. Wave Surge

Loss of wave surge at the bottom and the consequent deposition of silt will eventually alter the population of borers. Although it is possible that borers can live when buried under sand too thick for their siphons to project into the water, it is doubtful that normal growth and reproductive ability are not seriously derogated. Even assuming that the borers now living are not directly killed by the silting, future generations will find no suitable substrate to which they can attach. Areas that are not swept free of deposits will eventually be devoid of rock borers.

However, only a fraction of the exposed rock is located within the perimeter of the breakwaters, and tidal currents between the east and north breakwaters may be sufficient to prevent deposition of silt in that channel.

d. Food Supply

The expected decrease in the available planktonic food supply, when coupled with the filtering action of sand over the siphons, may hasten the demise of the rock borers in quiet water.

e. Pollution

The extent of damage to the borers attributable to oil and gasoline spills, sewage, and solid wastes from 1,700 boats and their operators cannot be predicted.

VII. SUGGESTIONS FOR FURTHER STUDY

The results of this study suggest several areas where further study is appropriate. The most obvious work will be done after construction of the breakwaters to analyze the ecological impact on the area.

For the biochemist, an explanation of the boring mechanism, if any, of *Botula falcata* could confirm or deny this author's suppositions concerning that species.

For the geologist, a more detailed analysis of the exposed Miocene strata with respect to hardness and chemical composition might suggest answers to distributional anomalies left unresolved in this thesis.

APPENDIX A: TRANSECT MAPS

In this Appendix the distribution of the rock borers along with the character of the substrate is presented in two series of strip charts, one for each (C and D) transect. The plotting commences at the mean of higher high water line (MHHW) and proceeds seaward across the sand to the first exposed rock, then along the reference line to the 320-m mark. All specimen plotting is symbolic and information needed to interpret the charts is included in the following list.

1. The words no, solitary, occasional, several, many, large numbers, colony, dense colony, and very dense colony are used to denote the relative abundance of the borers along the transects.

2. The 1 m width (50 cm either side of the reference line) has a horizontal exaggeration of 3.75:1 for ease in plotting.

3. Comments about substrate and borer distribution are in the left and right columns respectively.

4. The symbols used to represent the borers are:

○	*Parapholas*
△	*Chaceia*
☆	*Barnea*
□	*Zirfaea*
P	*Penitella* sp.
L,B	*Lithophaga* and *Botula*

The small arrows (↓) drawn across ledges point to the

low side. Dotted lines and ledges show the approximate boundaries of the type of substrate described in the left column.

5. Individual animals are not plotted except those labeled solitary. Symbols show only that the species is found in that location.

6. Tube worm mounds are frequently large piles of sand (20 ft^2 in area and 1 to 2 ft deep) surrounding the hook-shaped tubes of *Diopatra ornata*.

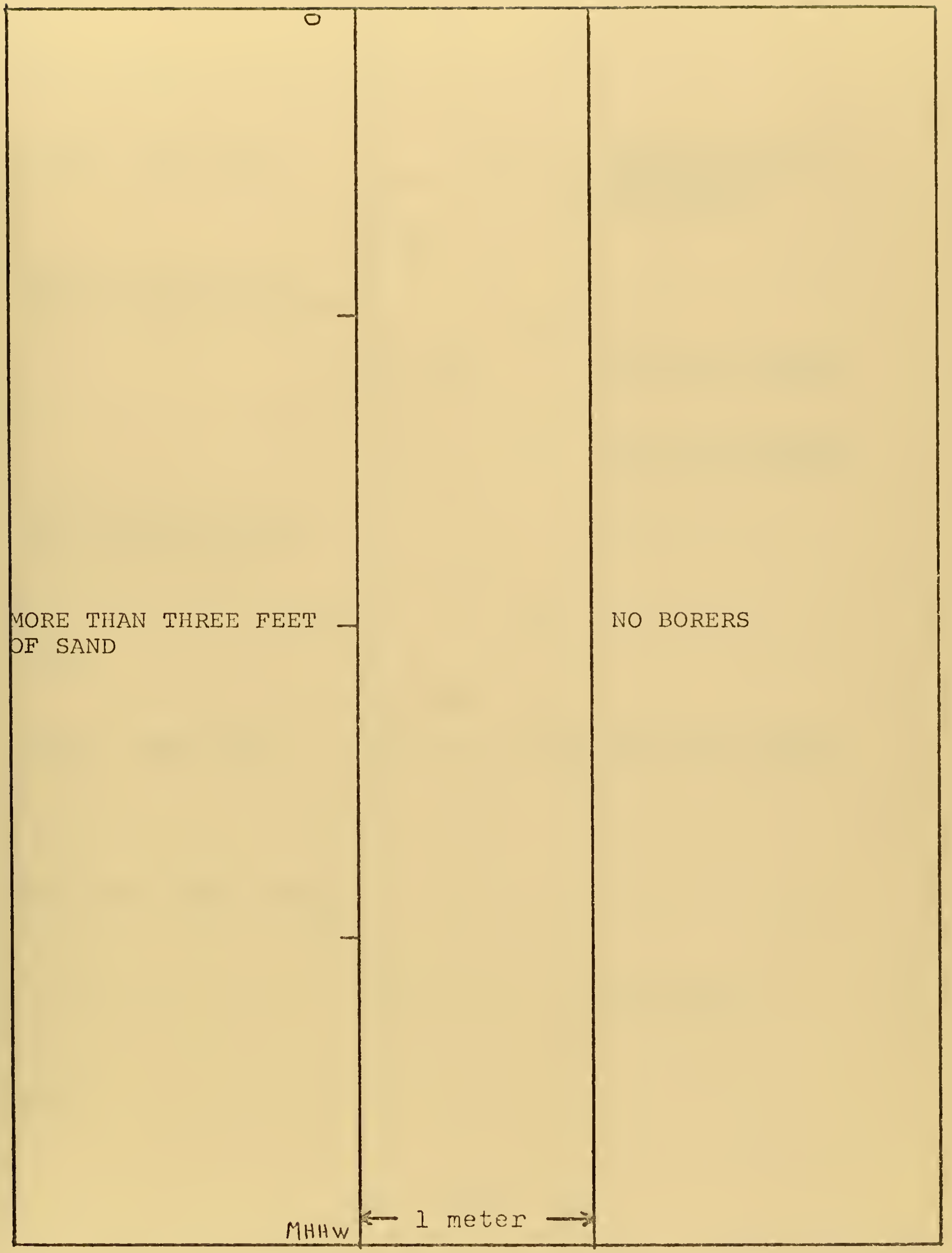

Figure 5. C MHHW - O
(approximately 170 m)

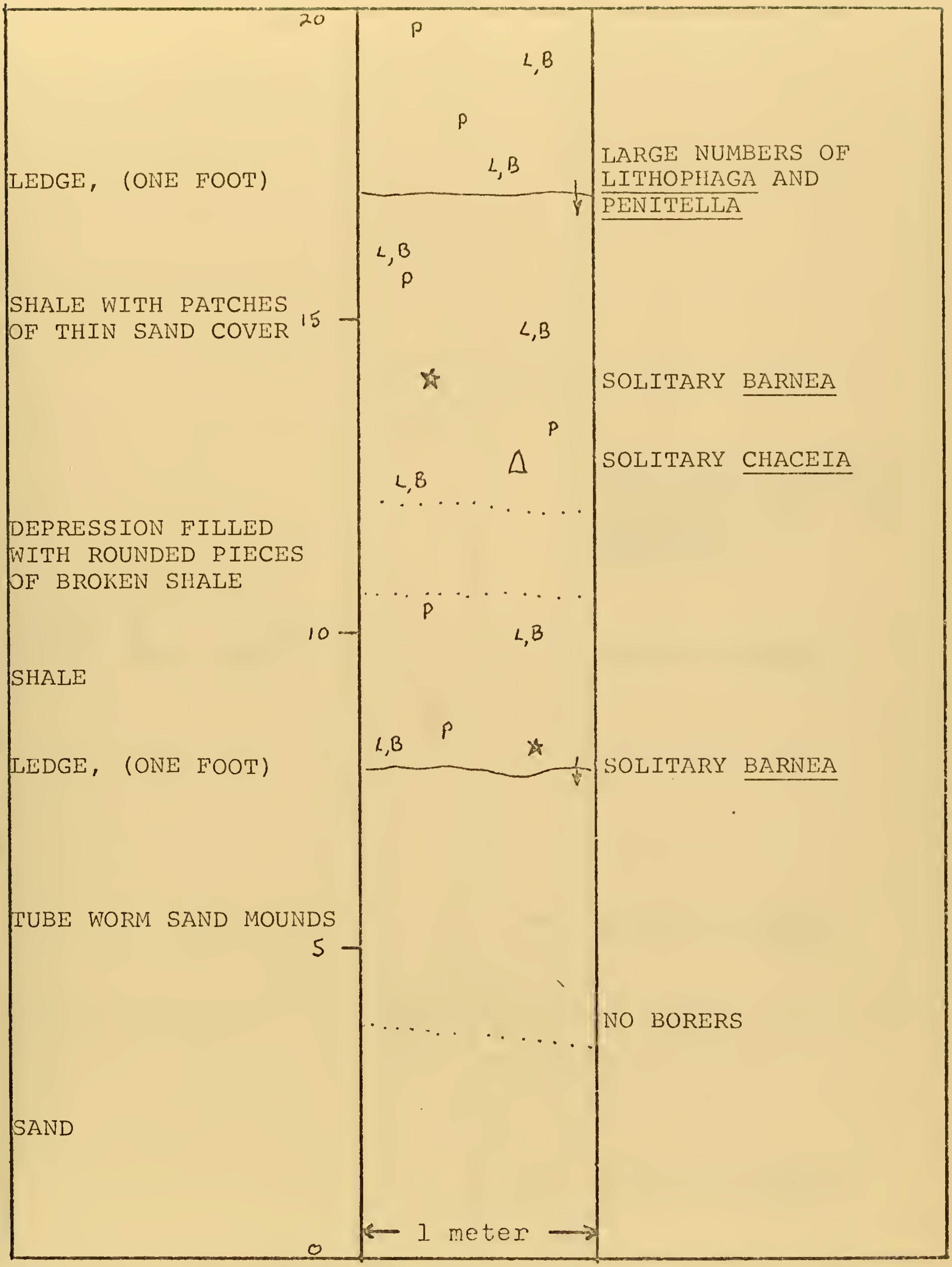

Figure 6. C O - 20
The ledge at the 7-m mark is the first exposed shale on the transect.

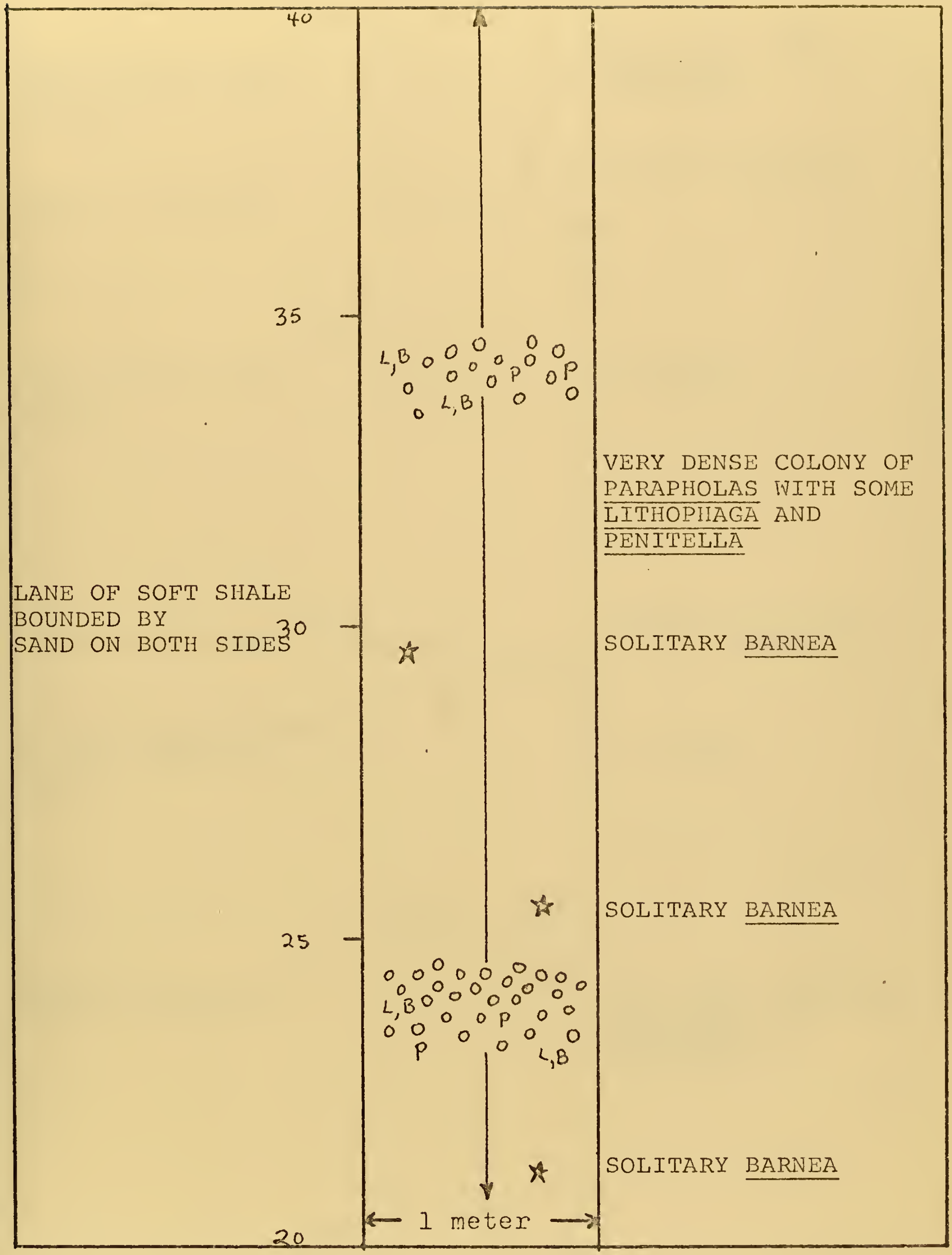

Figure 7. C 20 - 40
This is a striking contrast to the previous figure where there are no *Parapholas*.

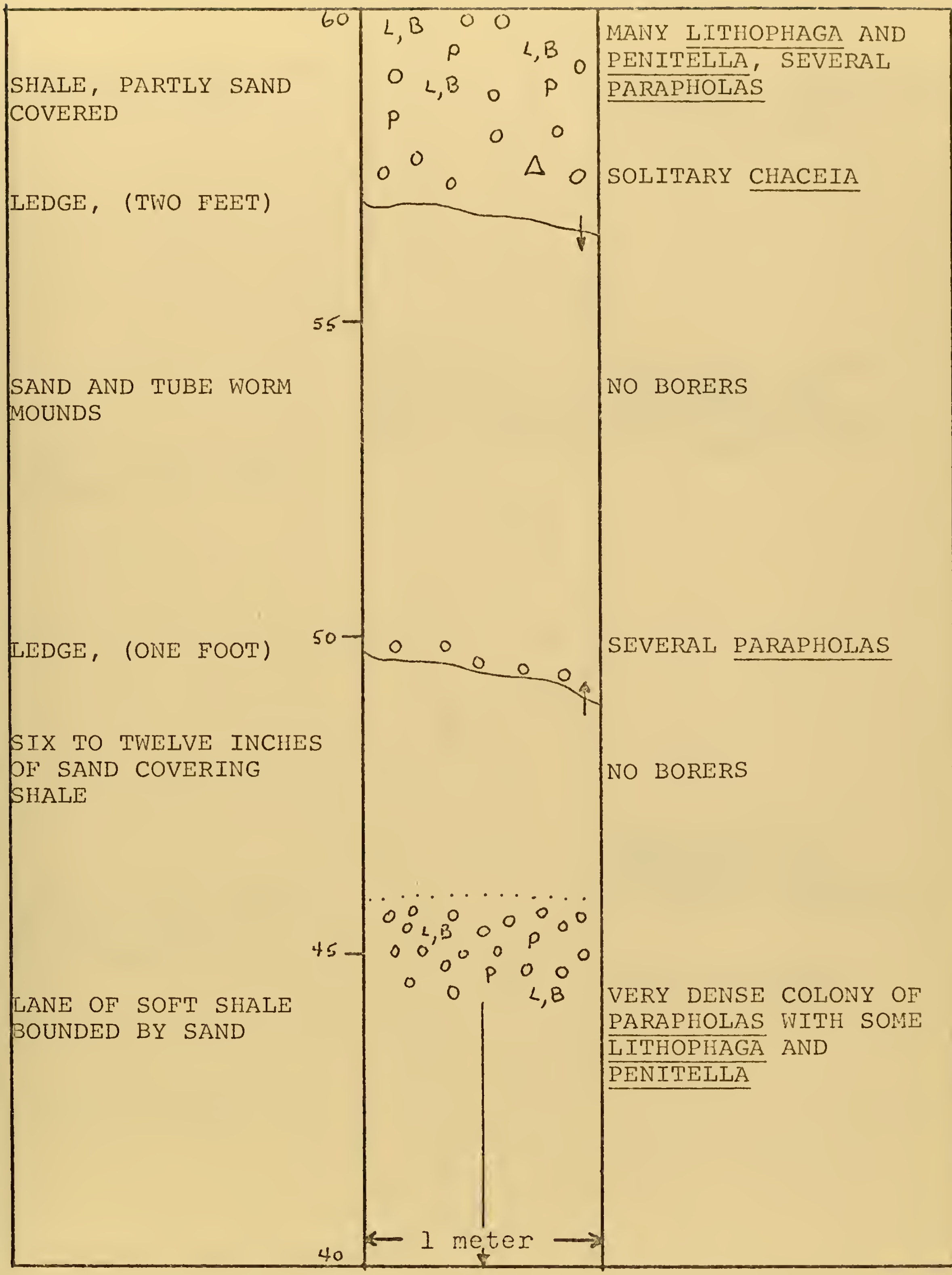

Figure 8. C 40 - 60

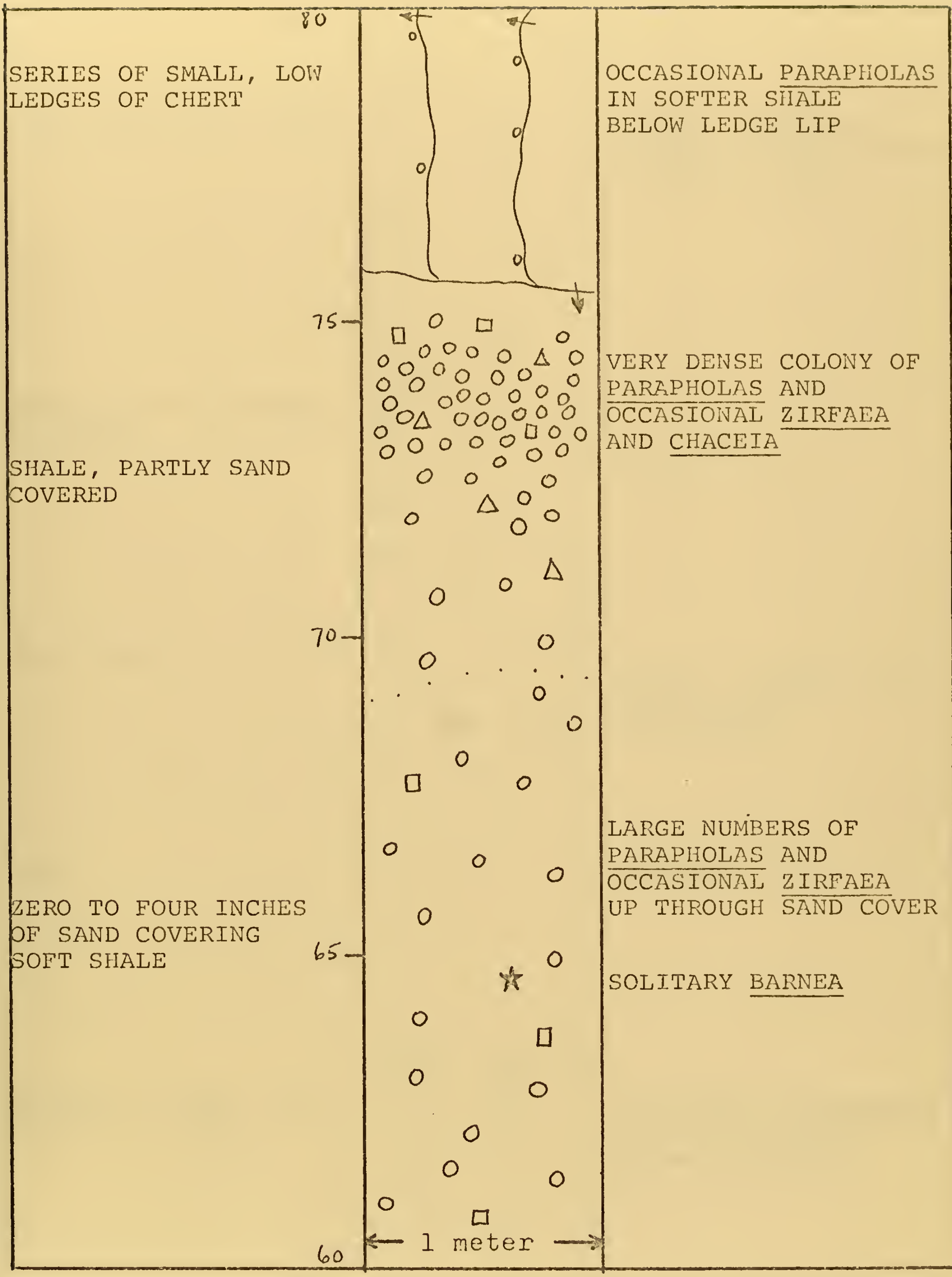

Figure 9. C 60 - 80

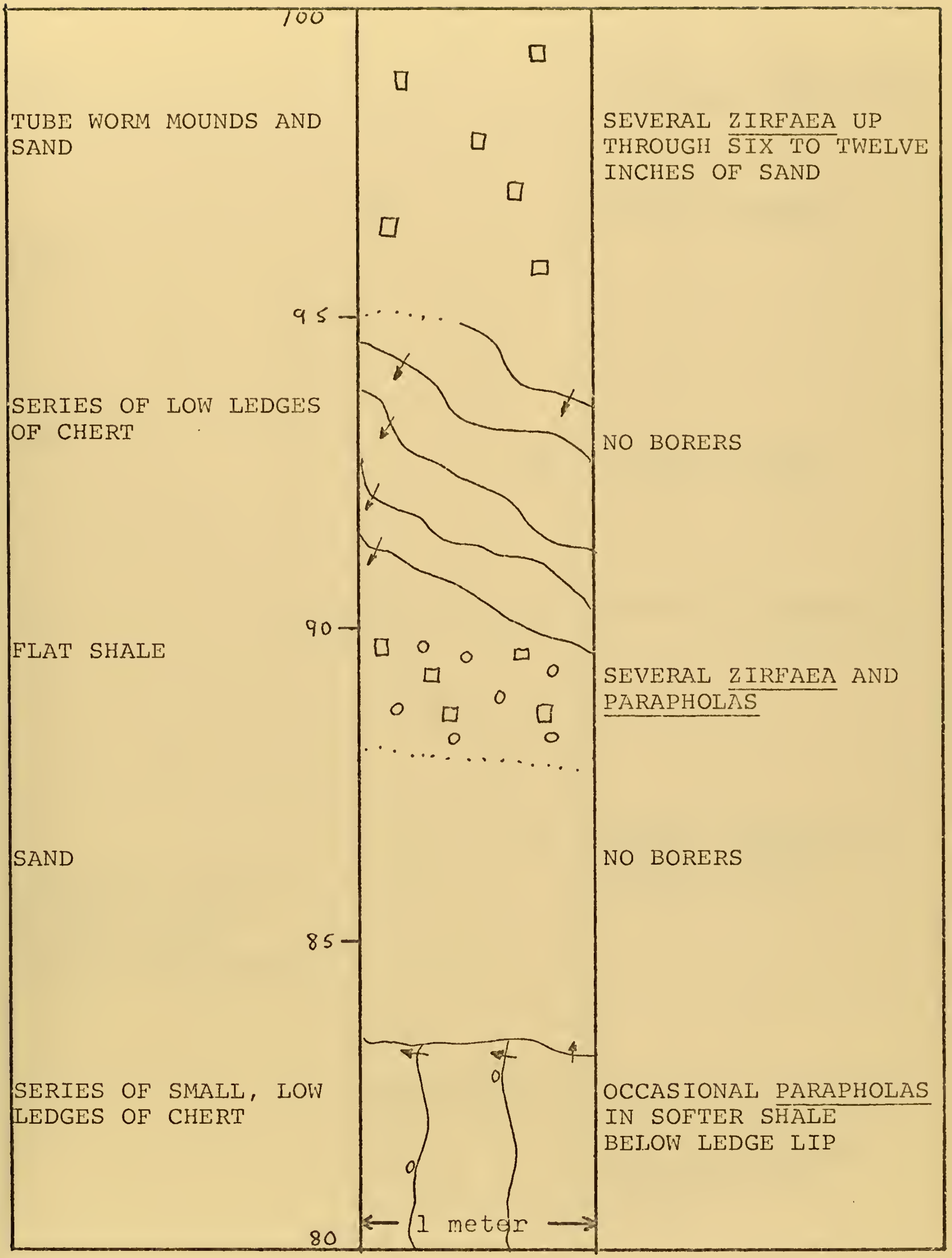

Figure 10. C 80 - 100

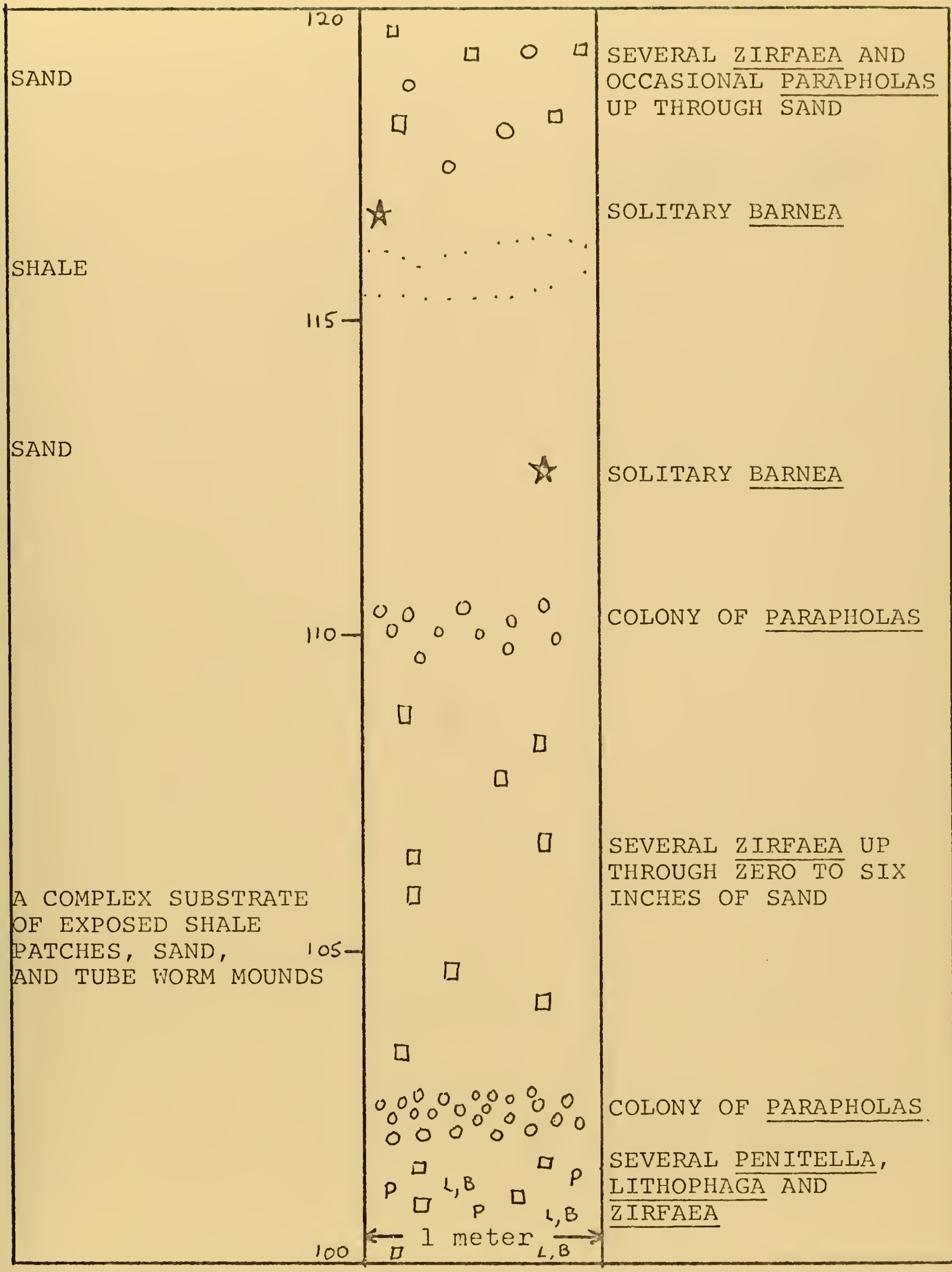

Figure 11. C 100 - 120

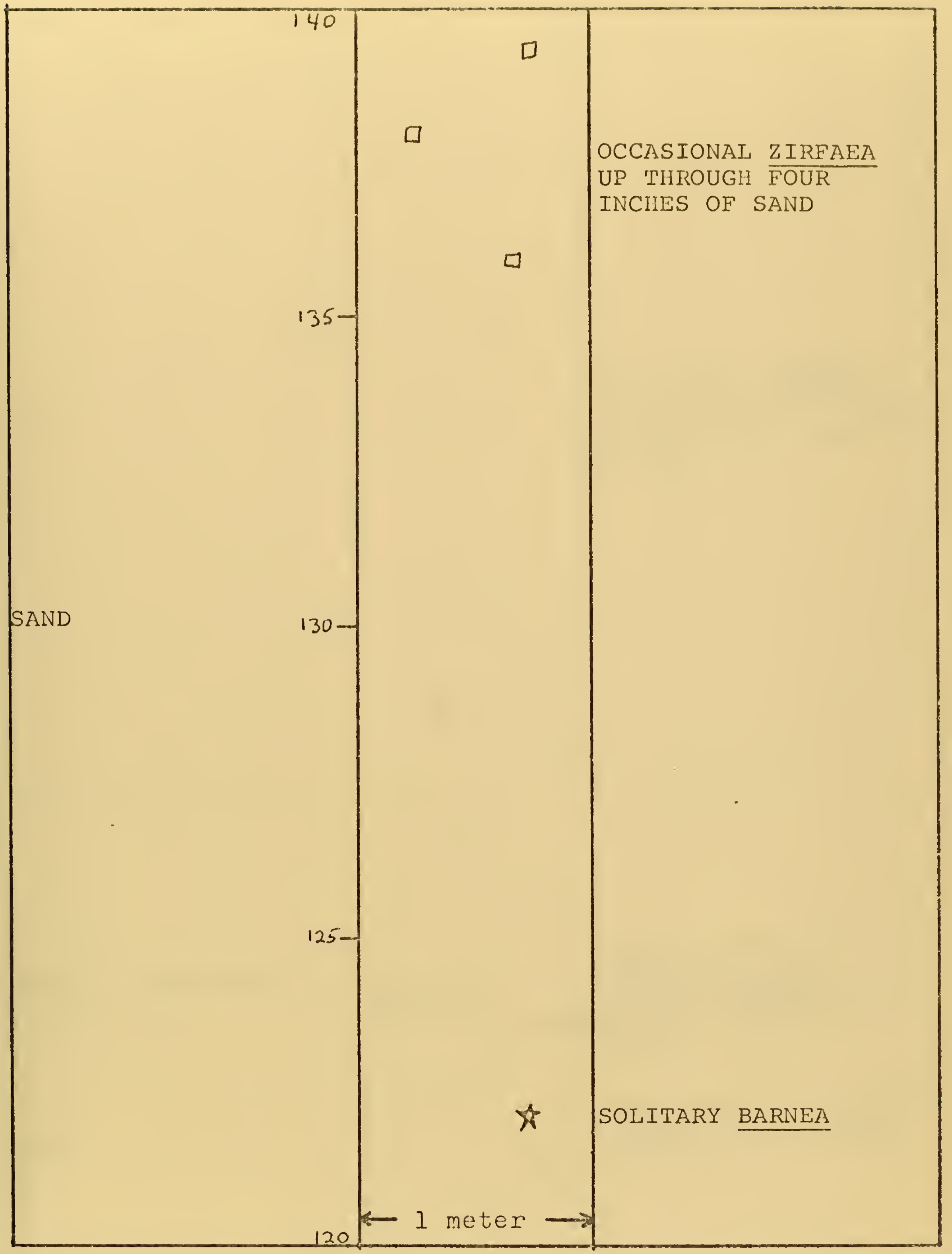

Figure 12. C 120-140

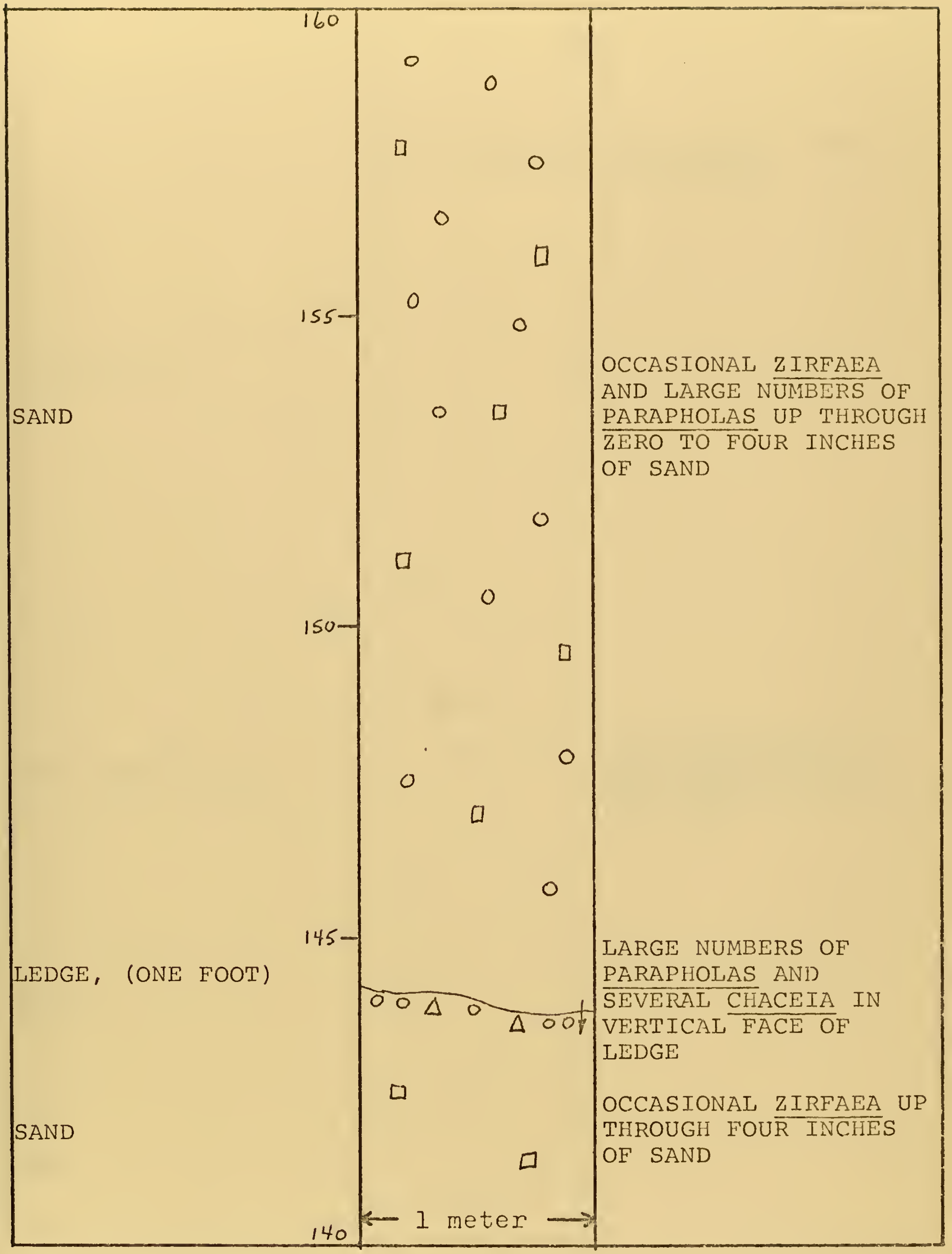

Figure 13. C 140-160

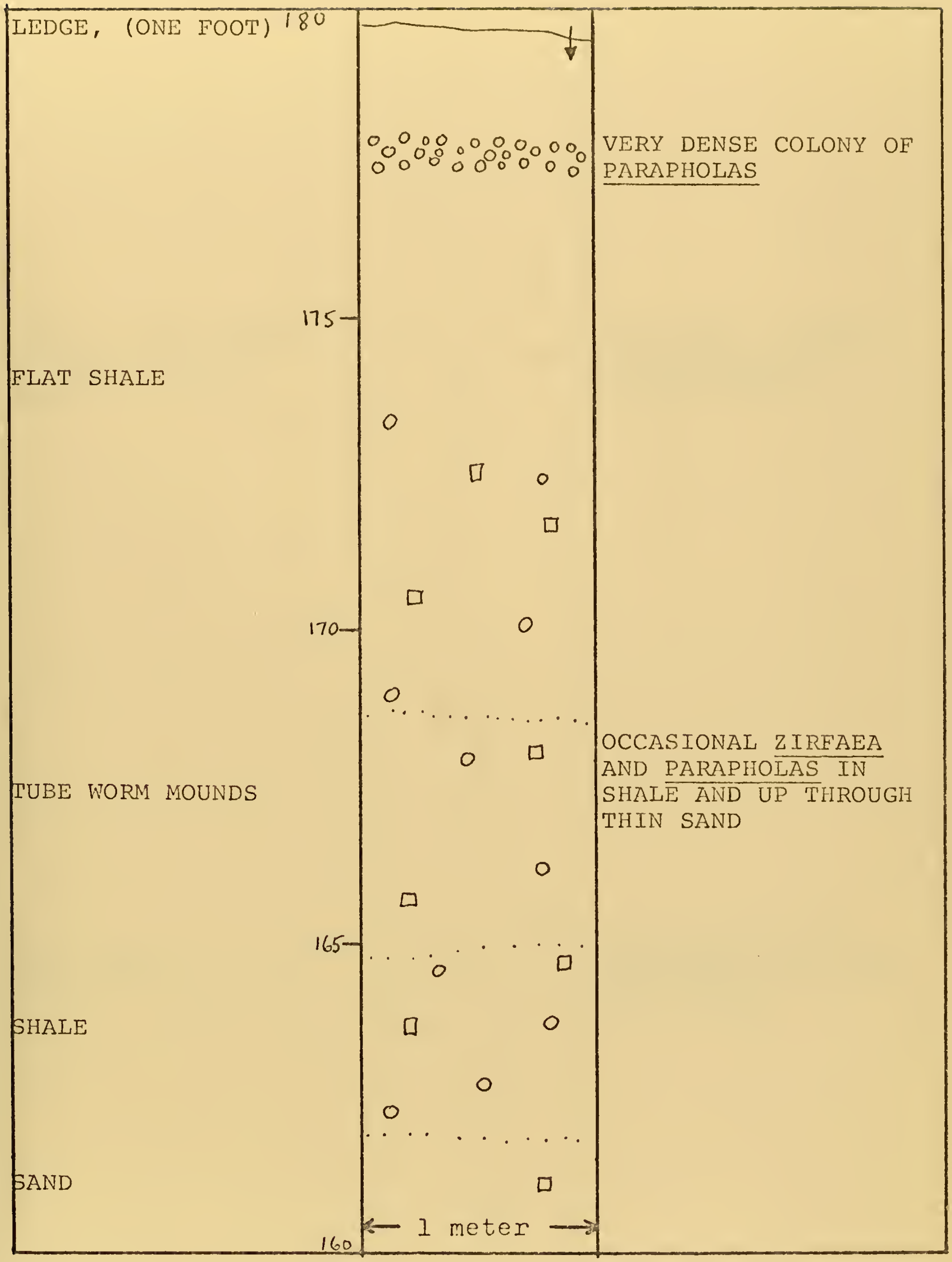

Figure 14. C 160-180

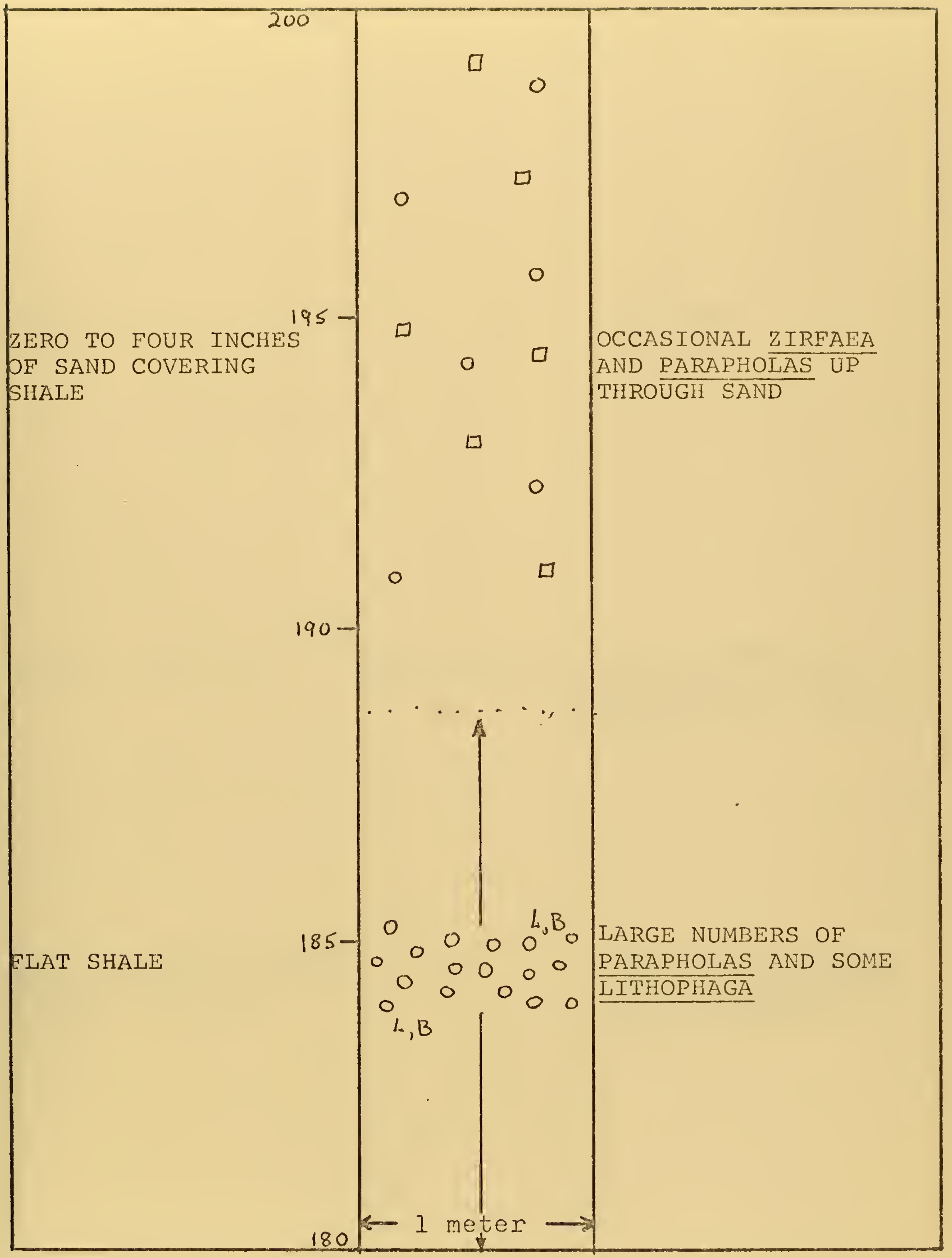

Figure 15. C 180-200

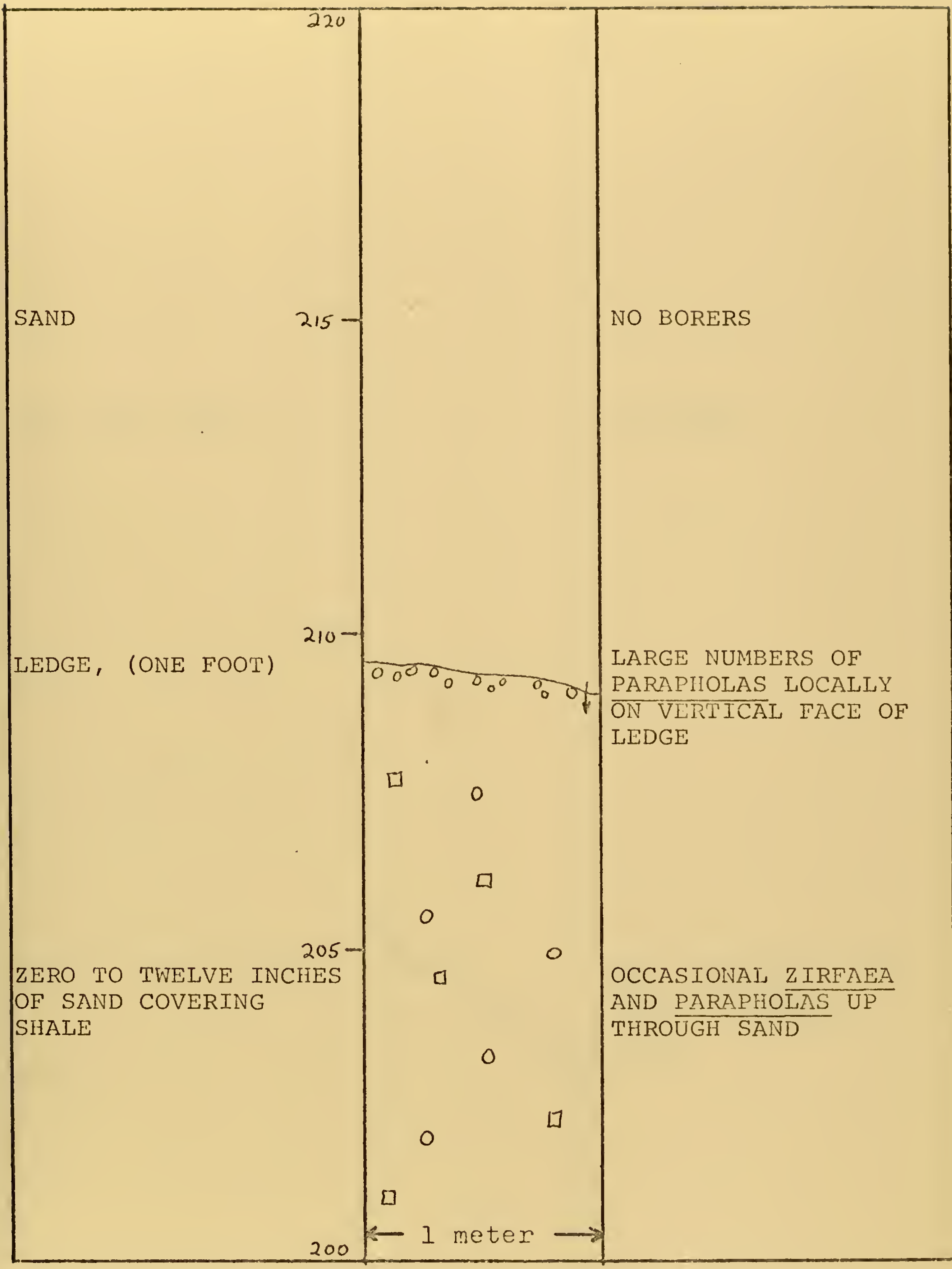

Figure 16. C 200-220

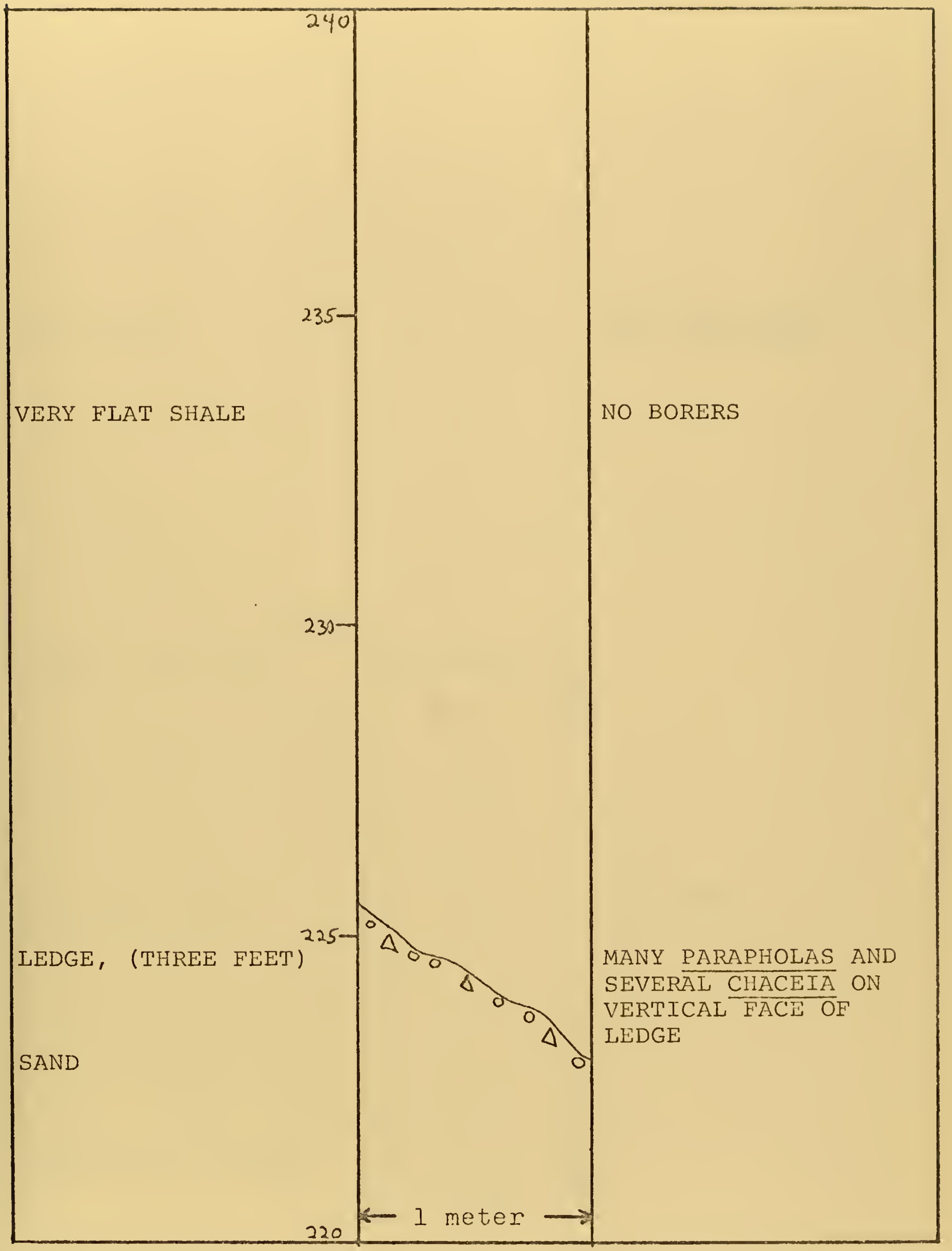

Figure 17. C 220-240

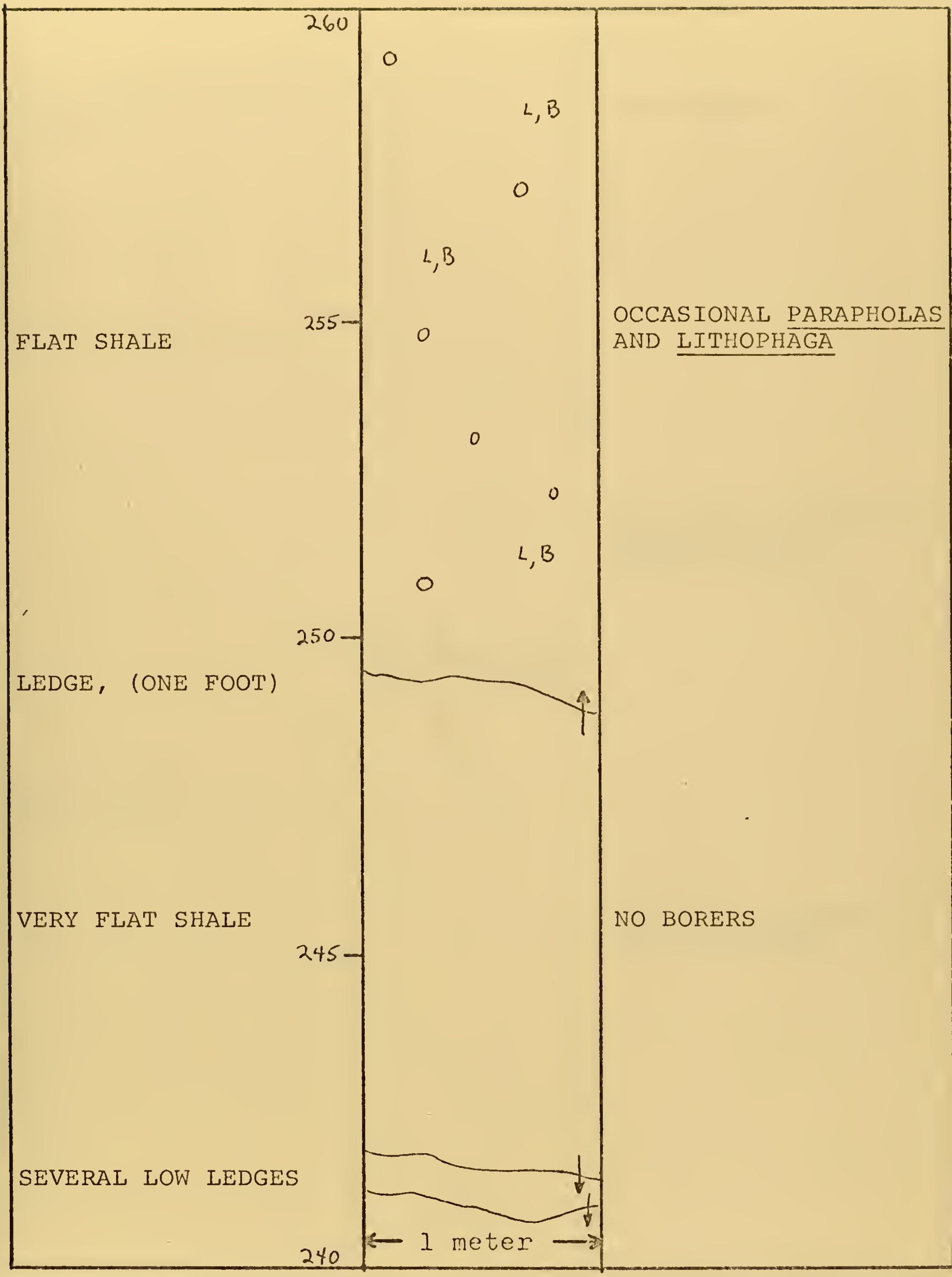

Figure 18. C 240-260

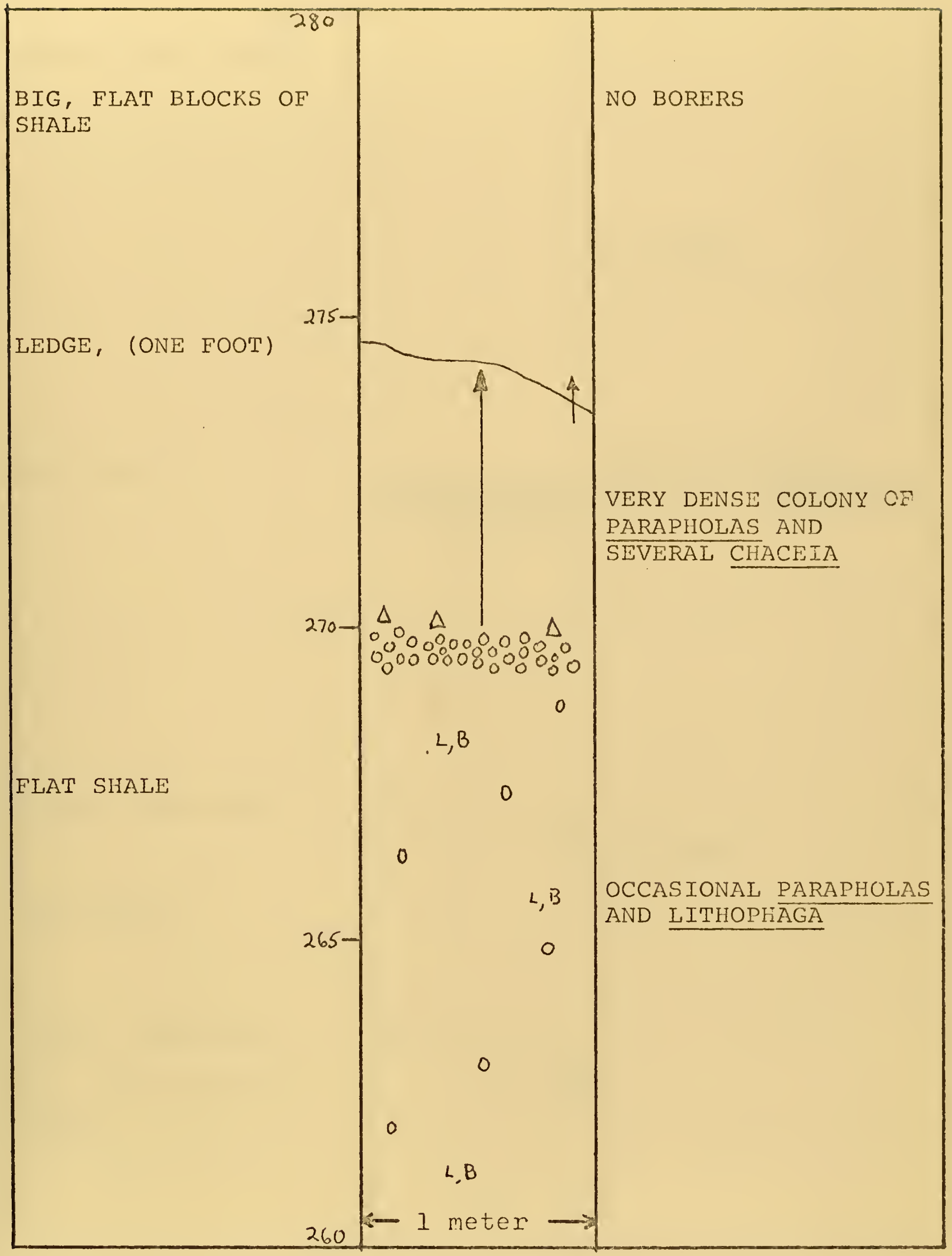

Figure 19. C 260-280

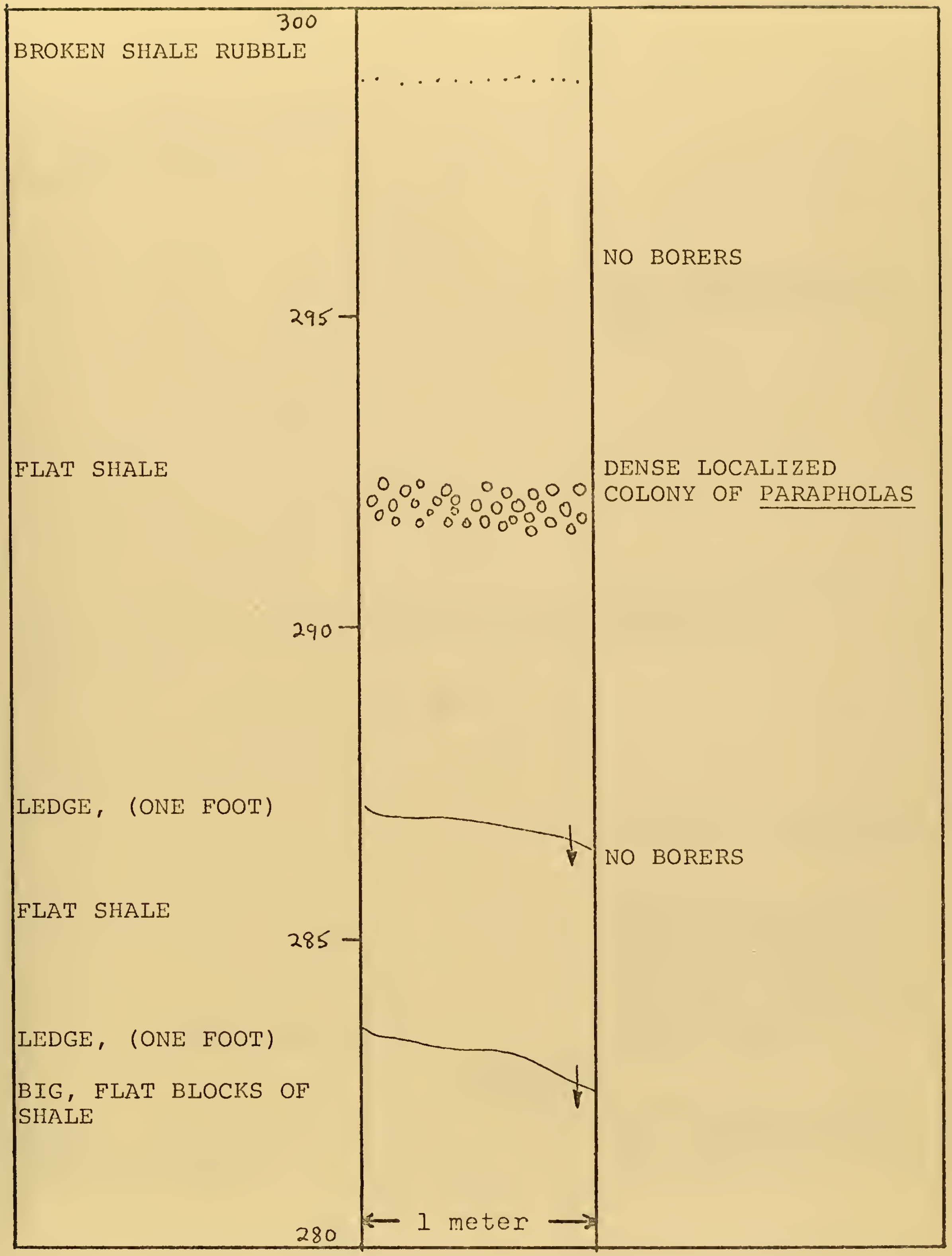

Figure 20. C 280-300

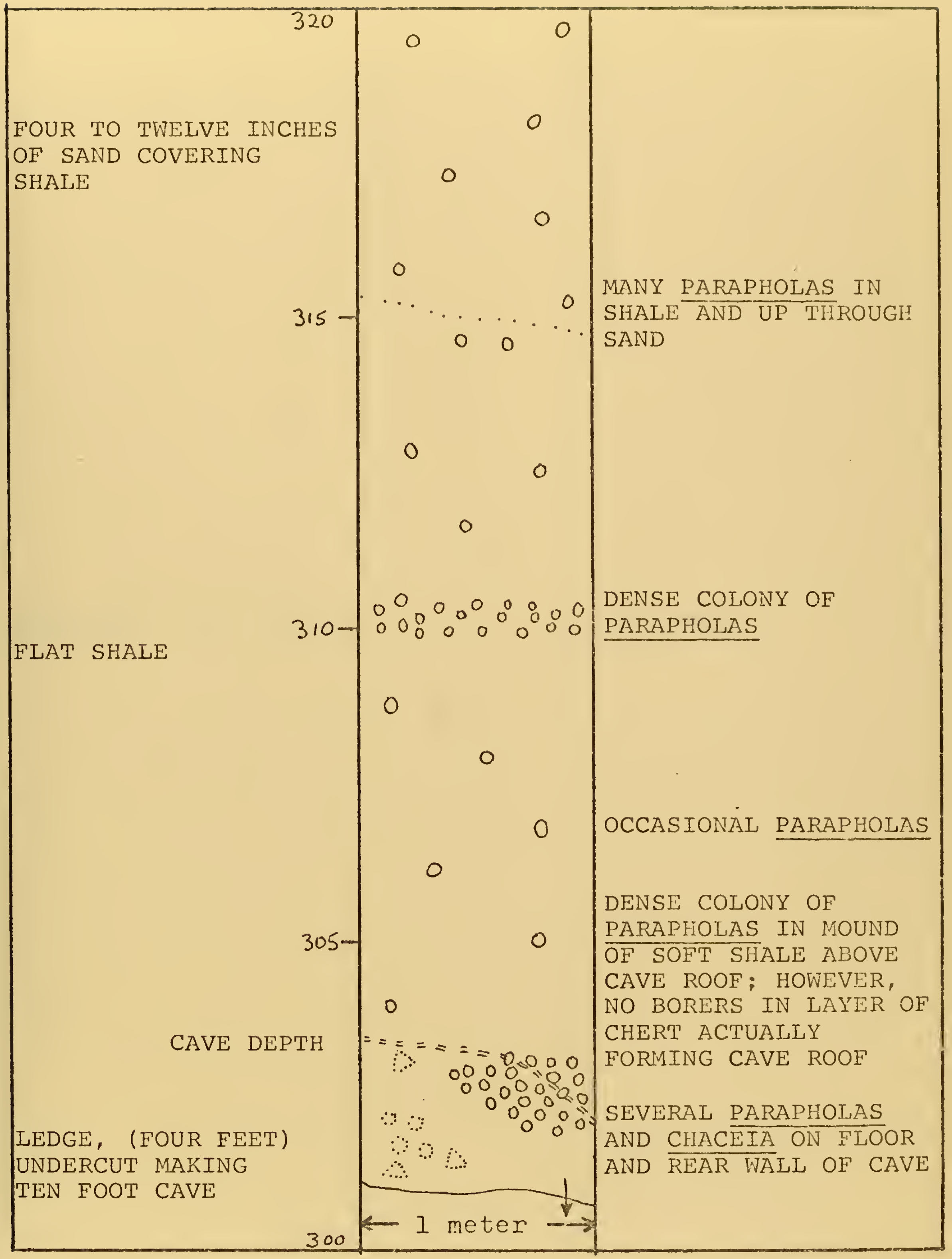

Figure 21. C 300-320

Figure 22. D MHHW - 0
(approximately 280 m)

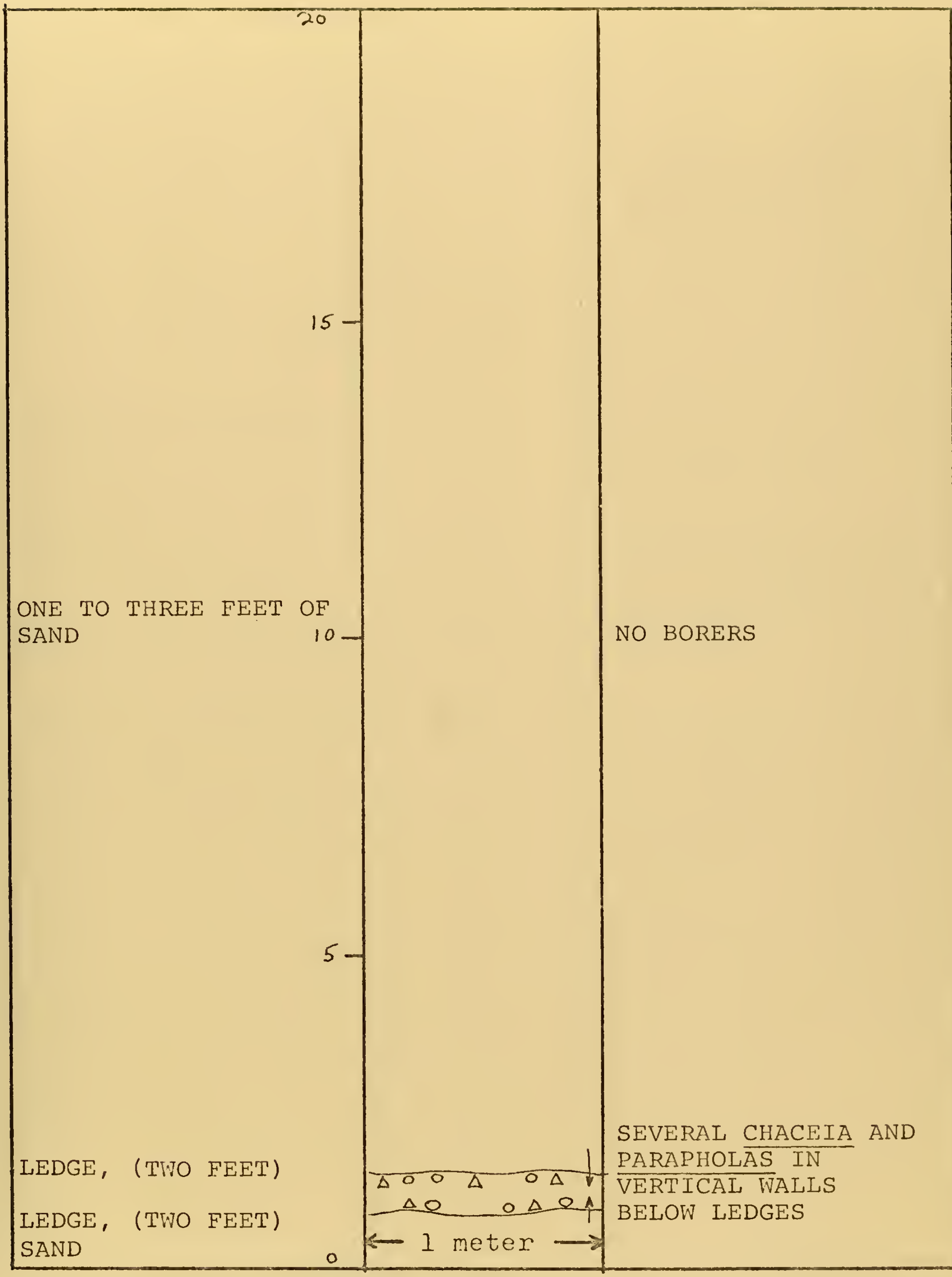

Figure 23. D 0-20
The ledges are the first exposed shale on D transect.

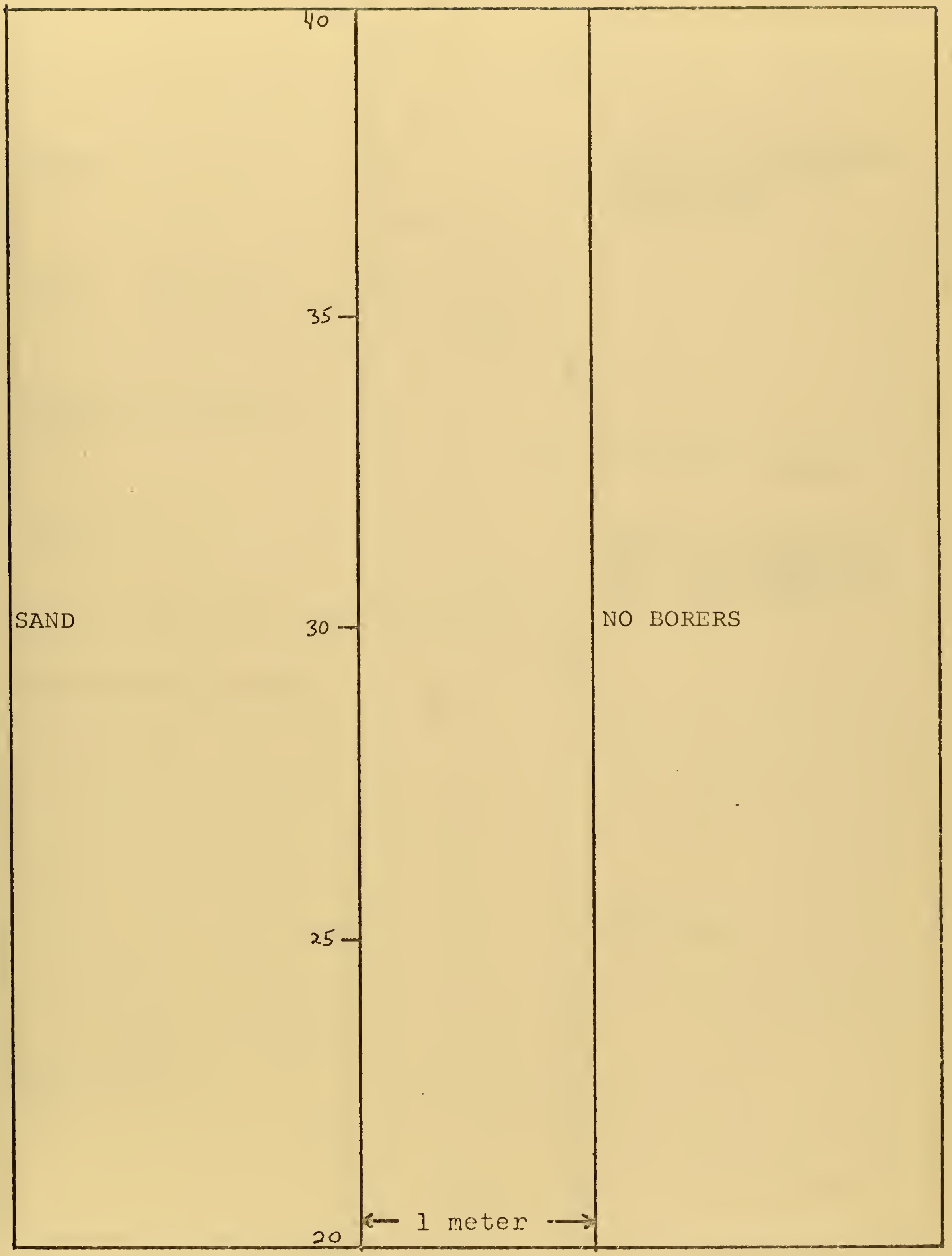

Figure 24. D 20-40

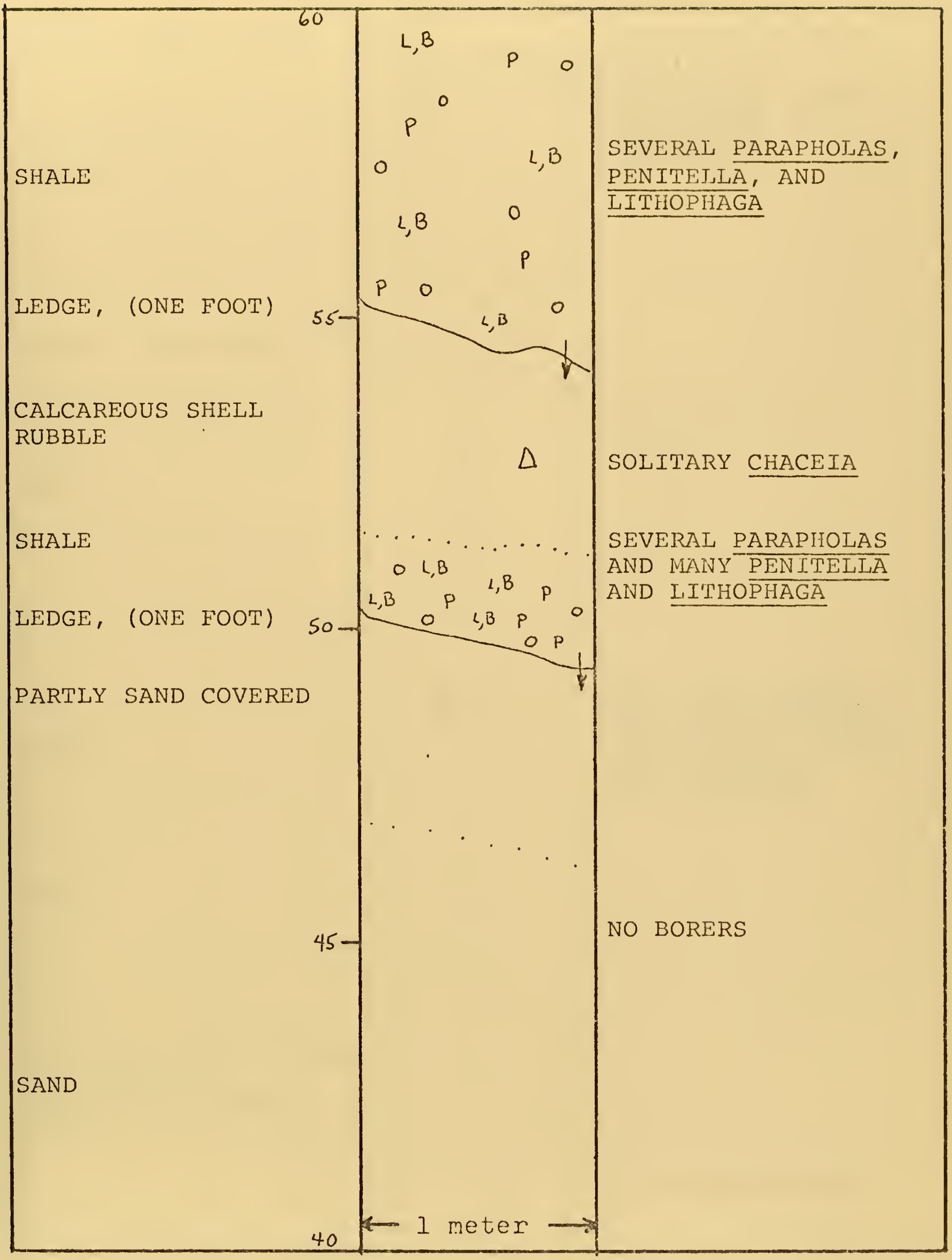

Figure 25. D .40-60

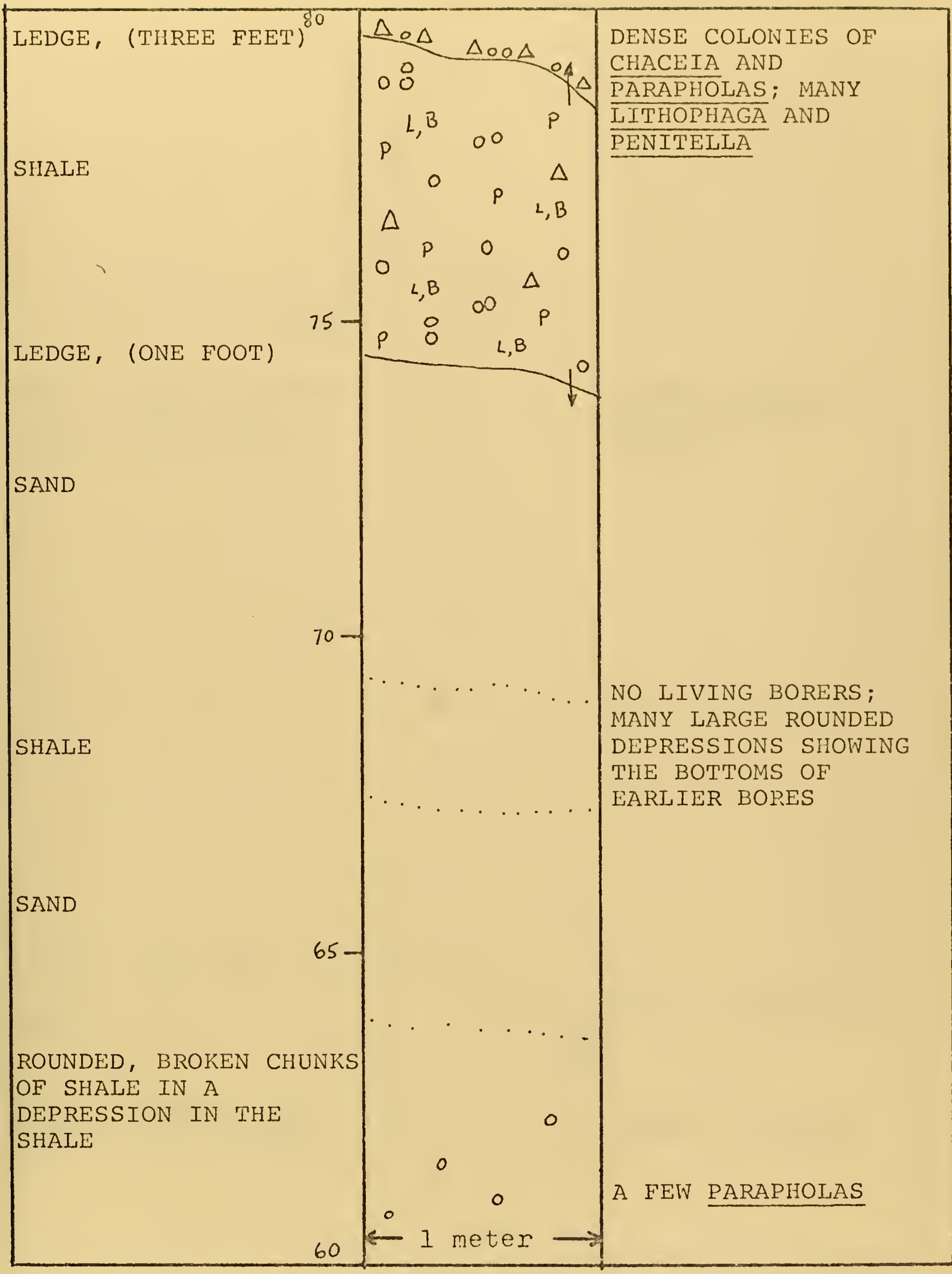

Figure 26. D 60-80

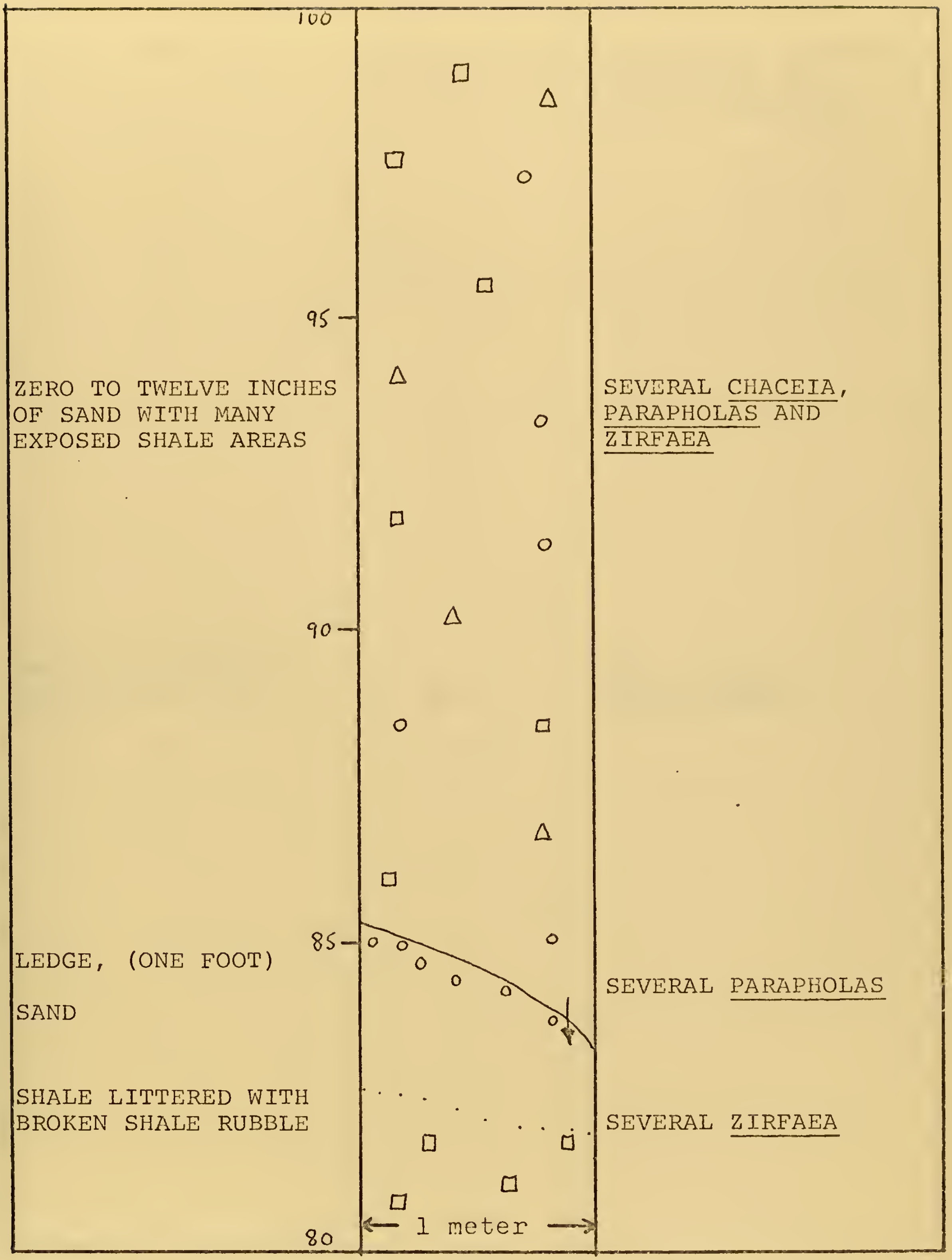

Figure 27. D 80-100

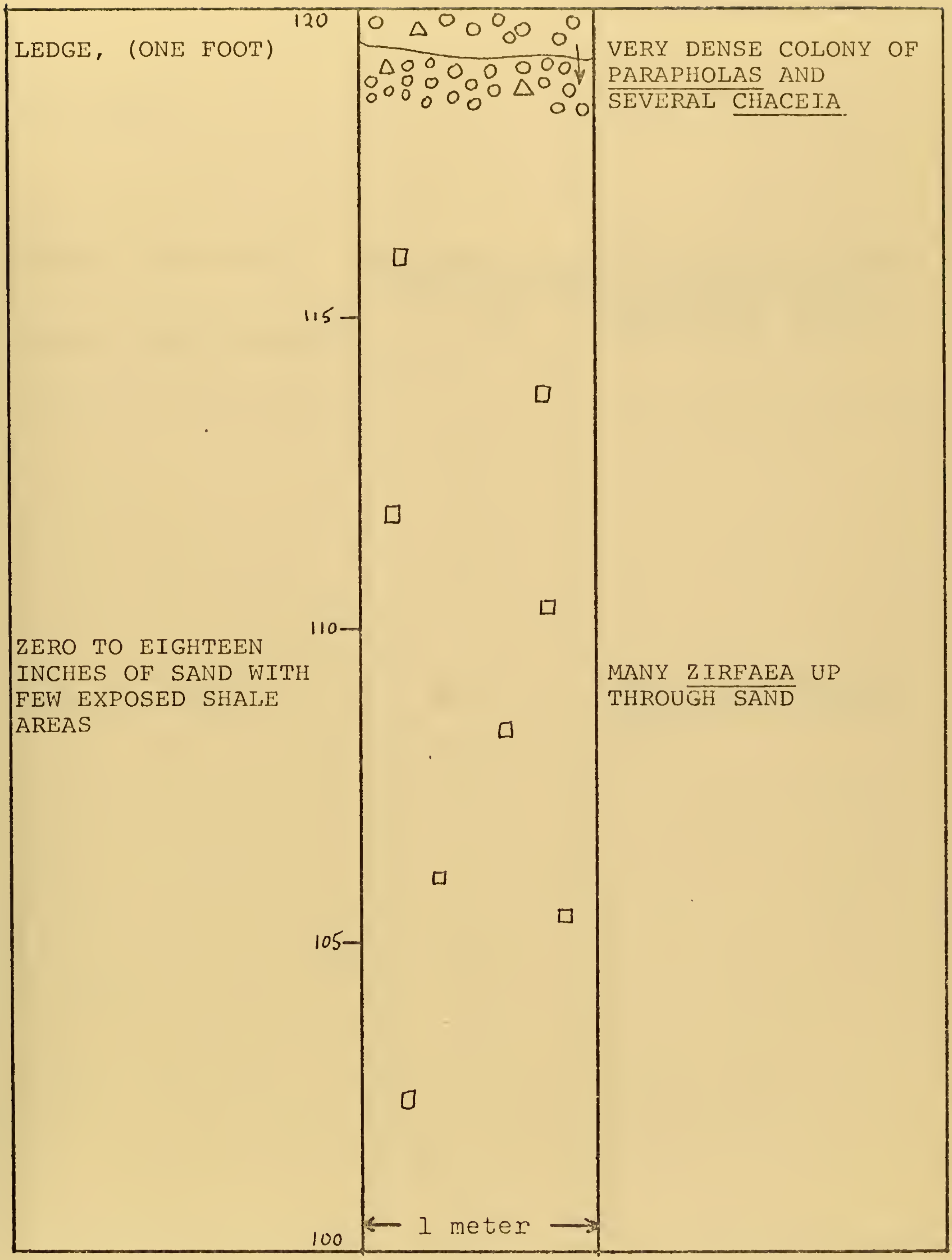

Figure 28. D 100-120

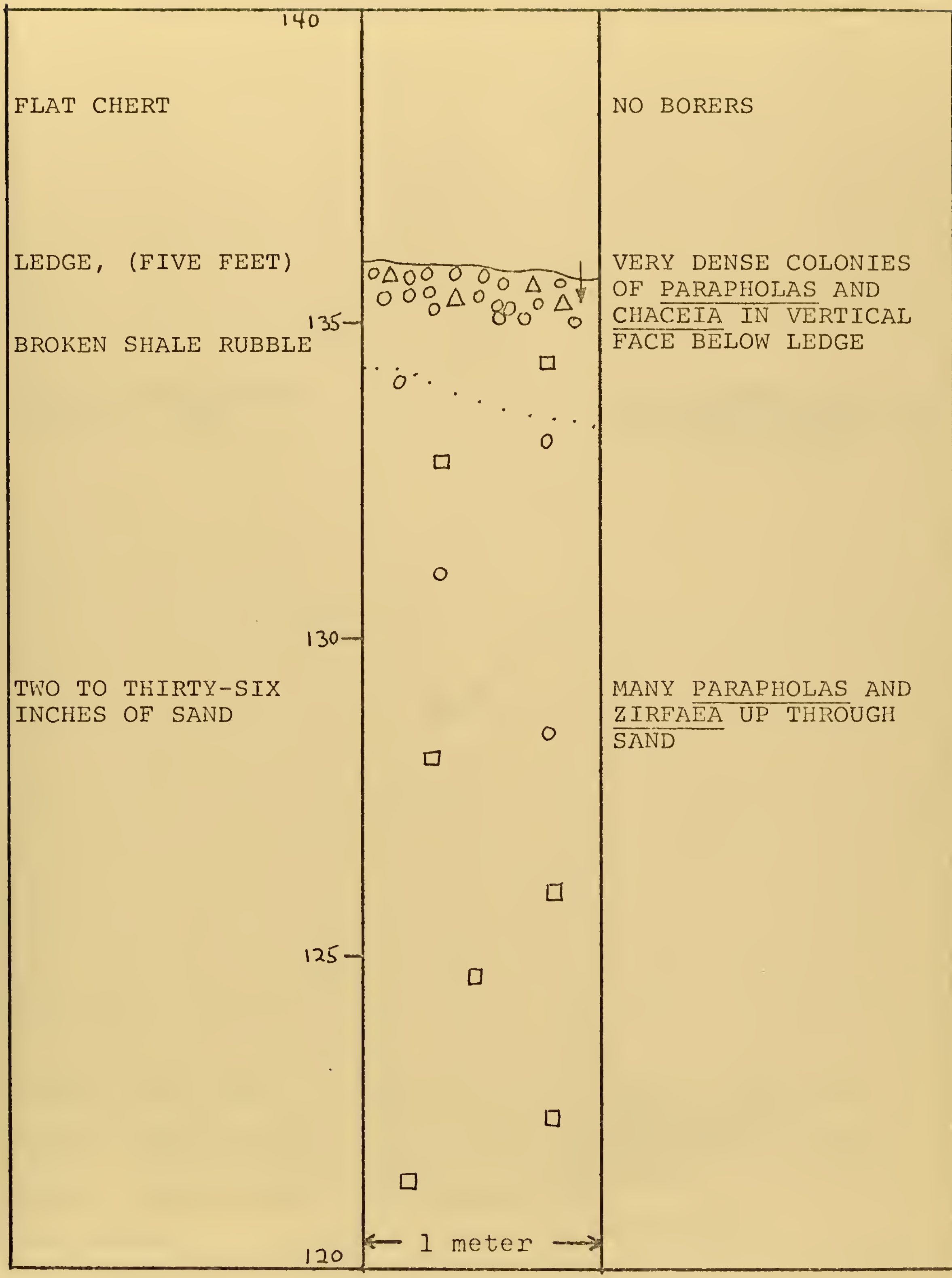

Figure 29. D 120-140

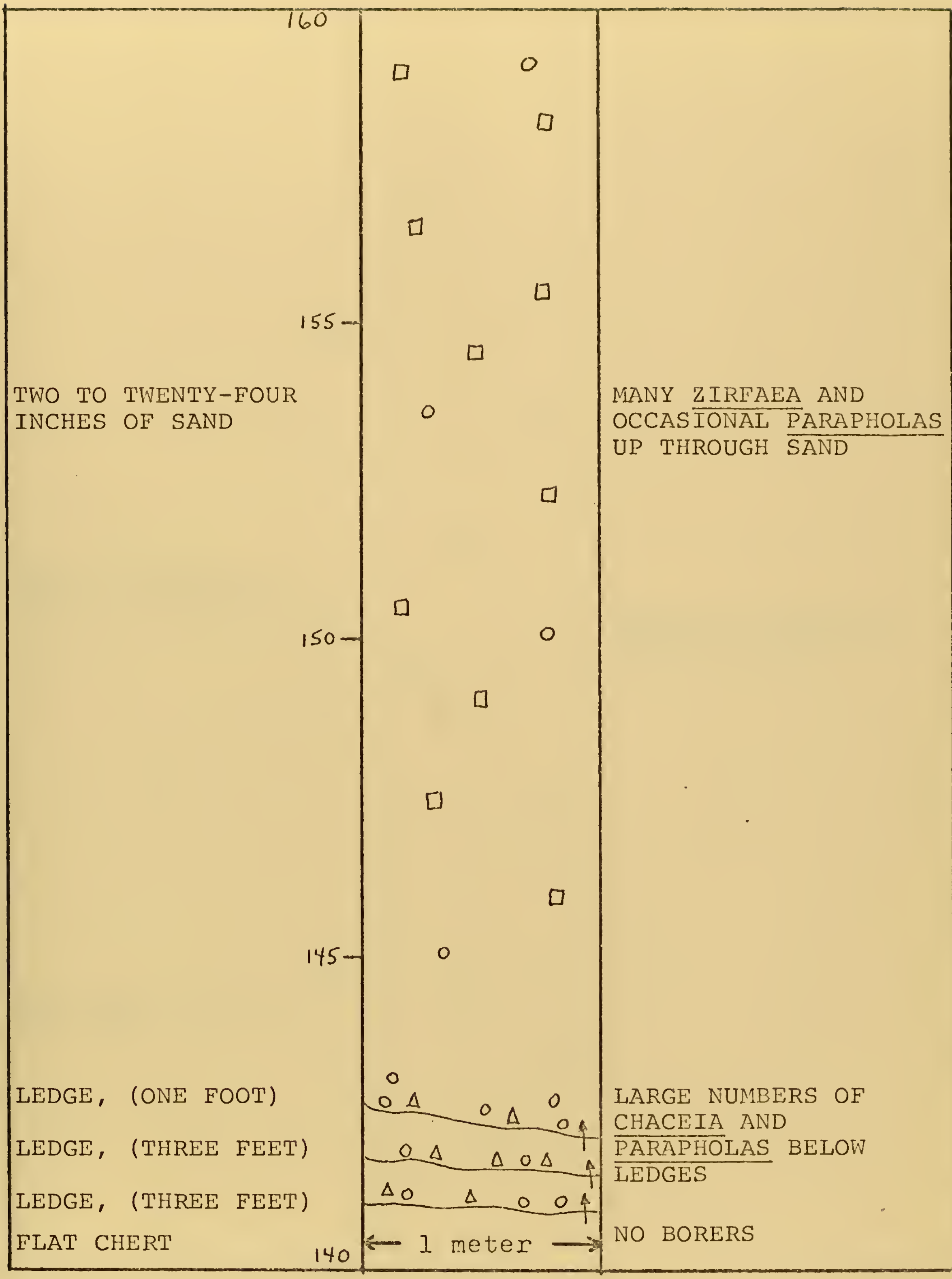

Figure 30. D 140-160

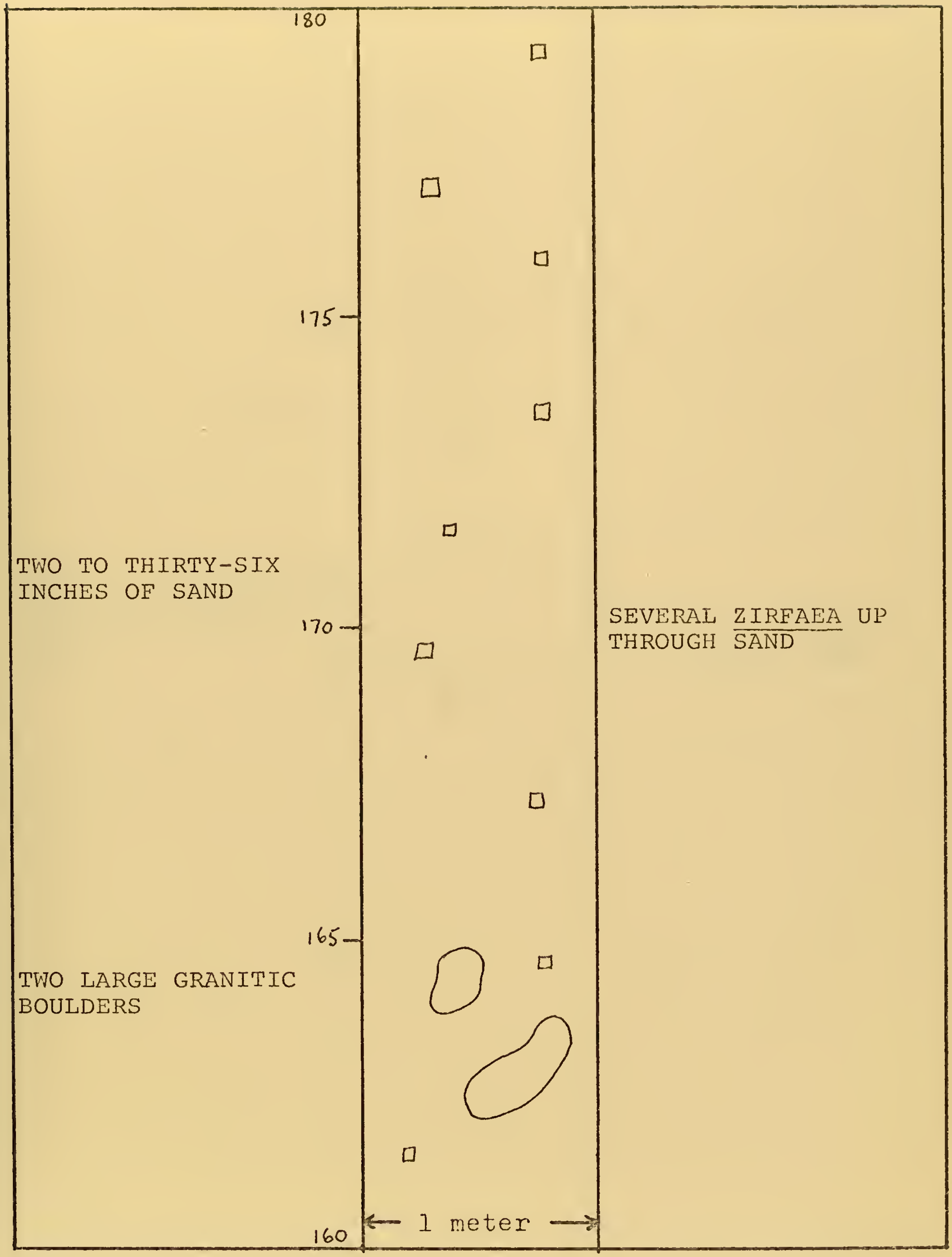

Figure 31. D · 160-180

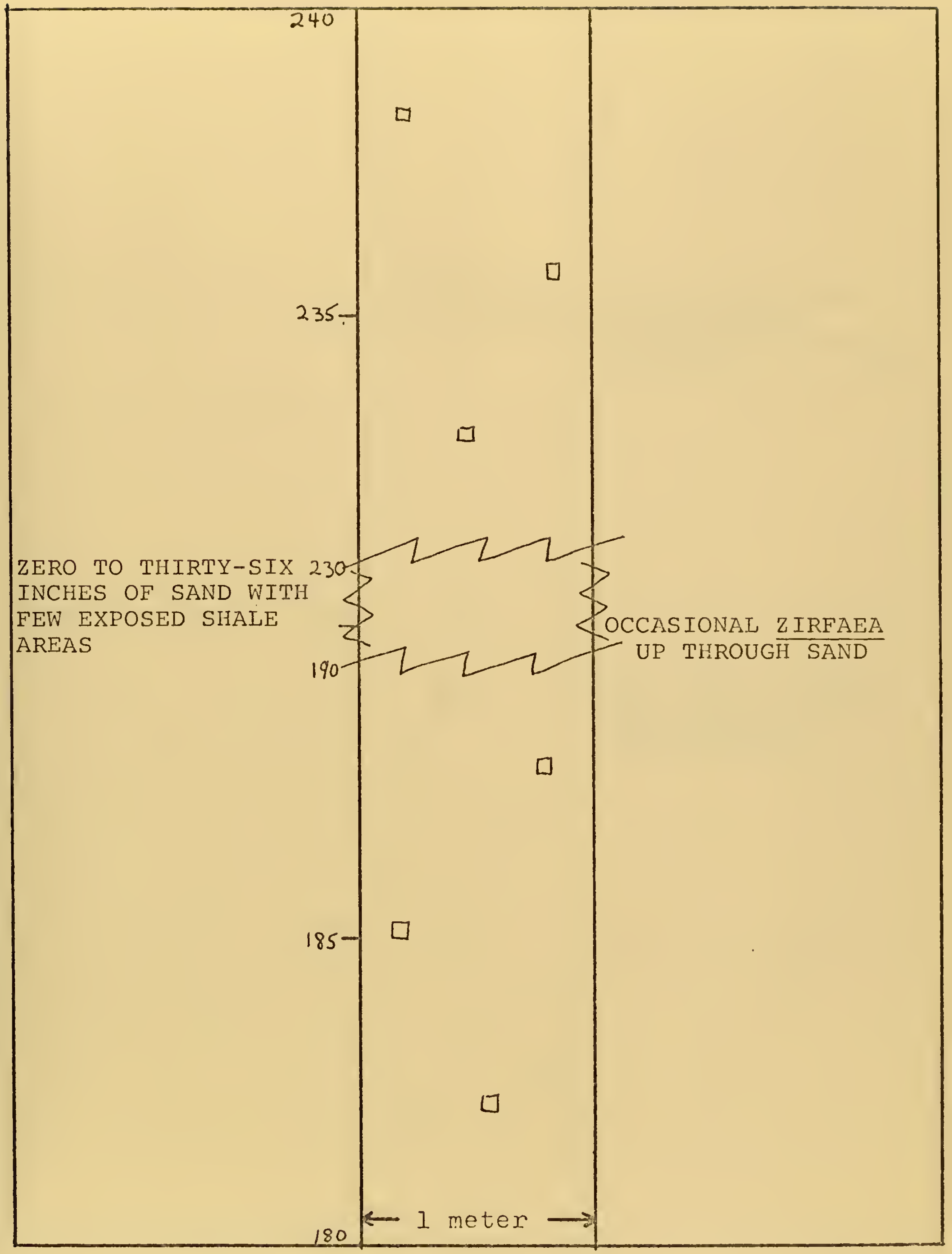

Figure 32. D 180-240

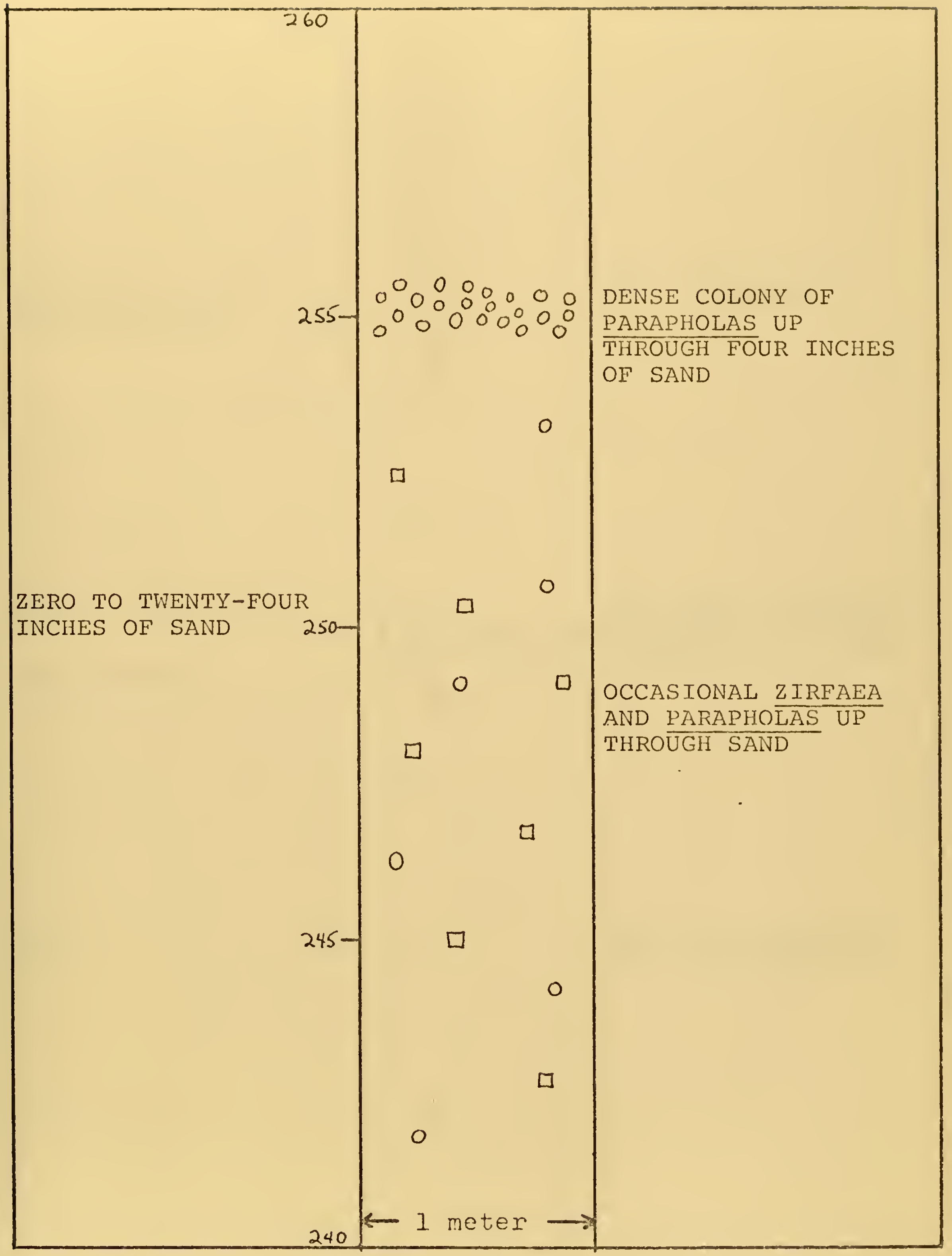

Figure 33. D 240-260

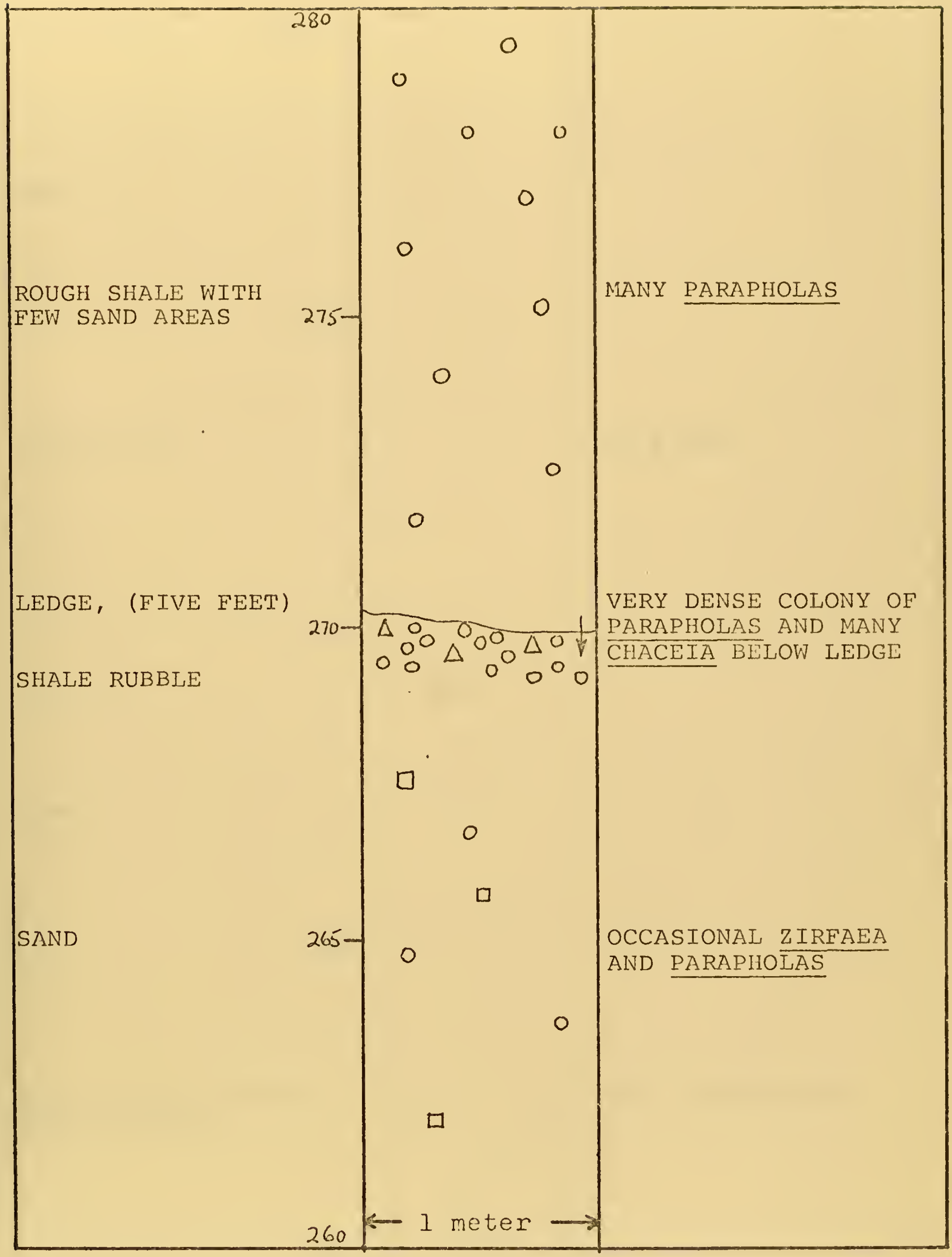

Figure 34. D 260-280

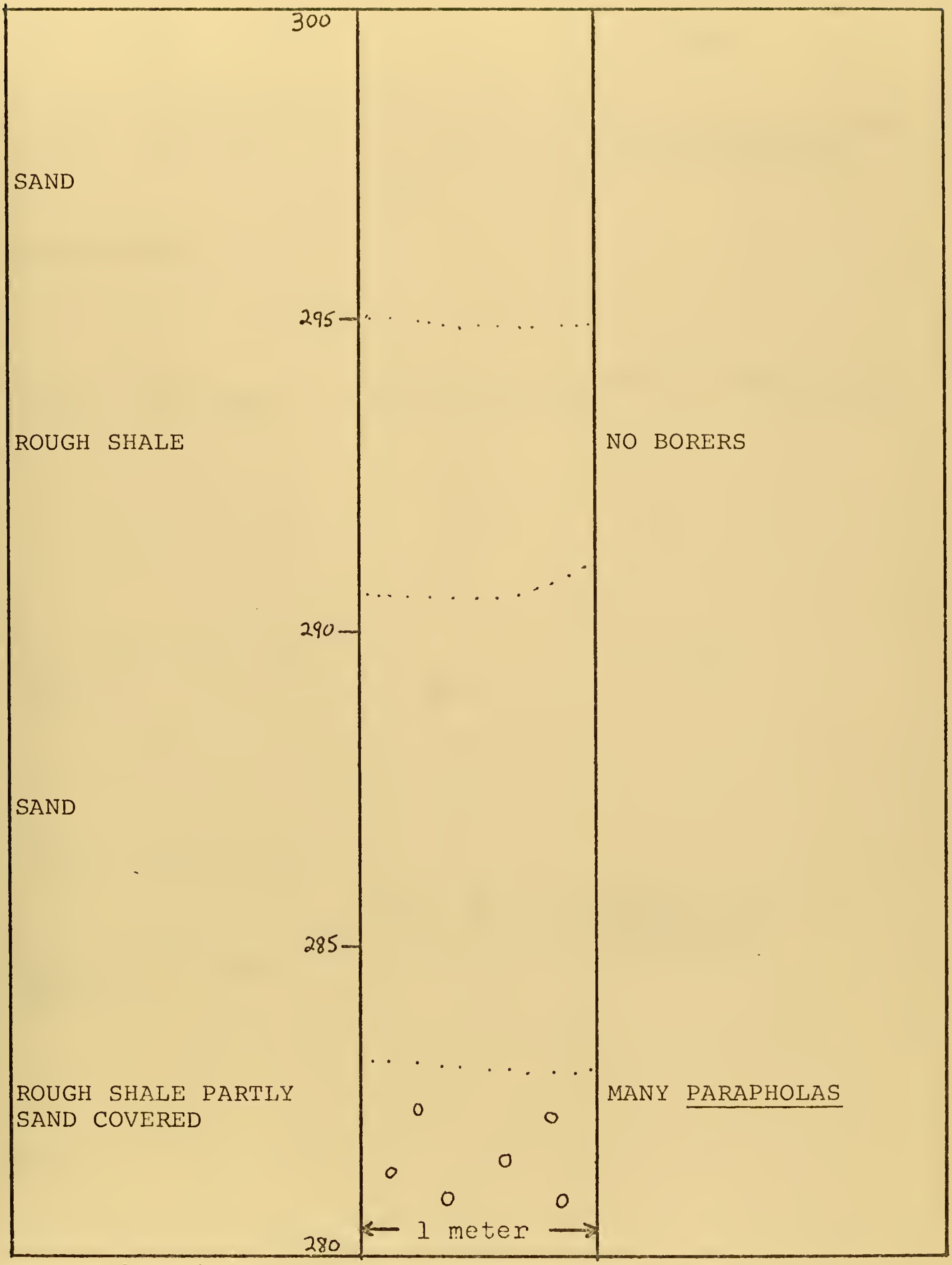

Figure 35. D 280-300

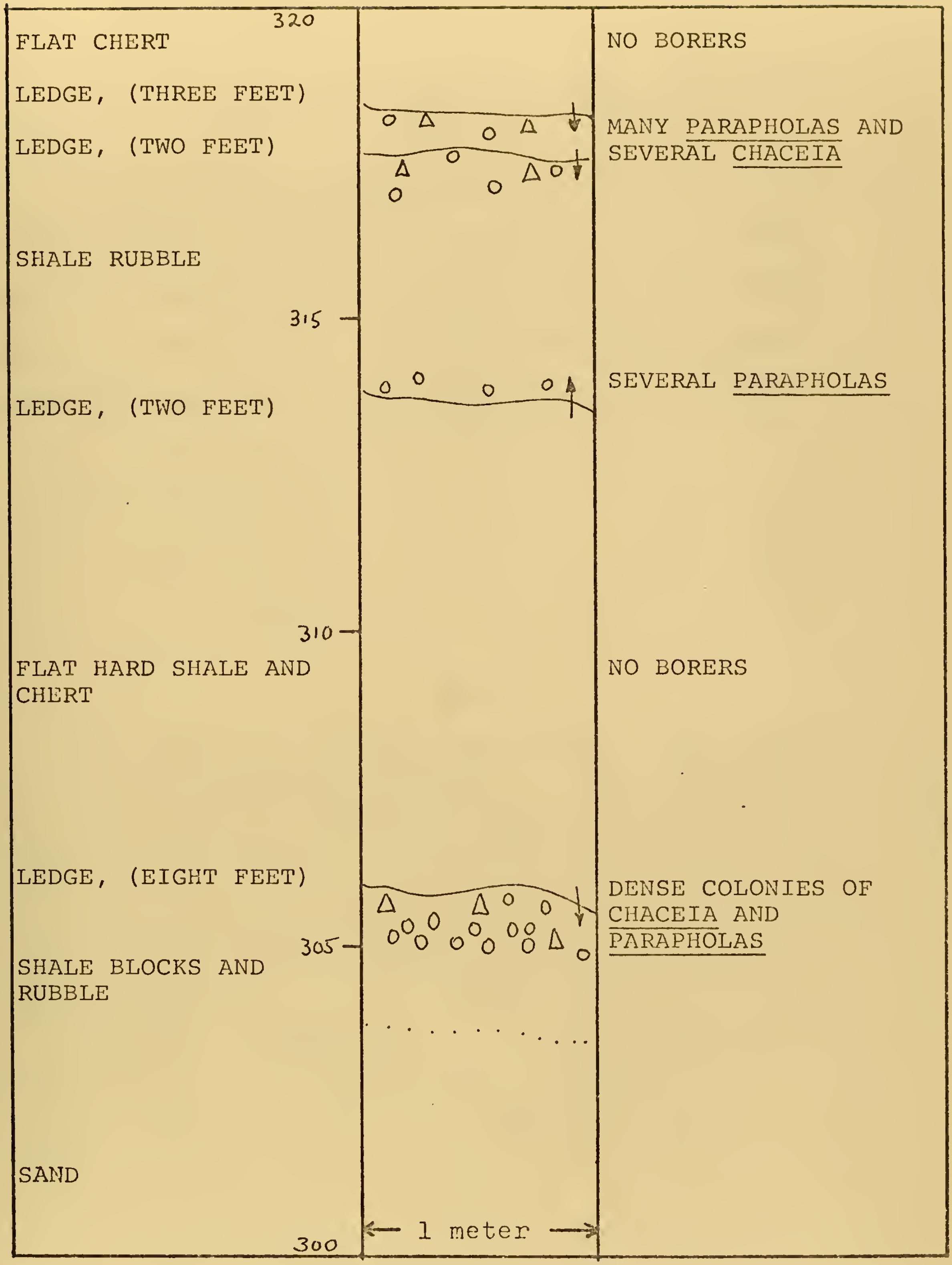

Figure 36. D 300-320

APPENDIX B: SELECTED PHOTOGRAPHS

In this Appendix photographs are presented of most of the species described in section V of this thesis. For the borers whose siphons were too small to photograph, pictures of the valves are presented. Degree of magnification or an actual dimension is provided.

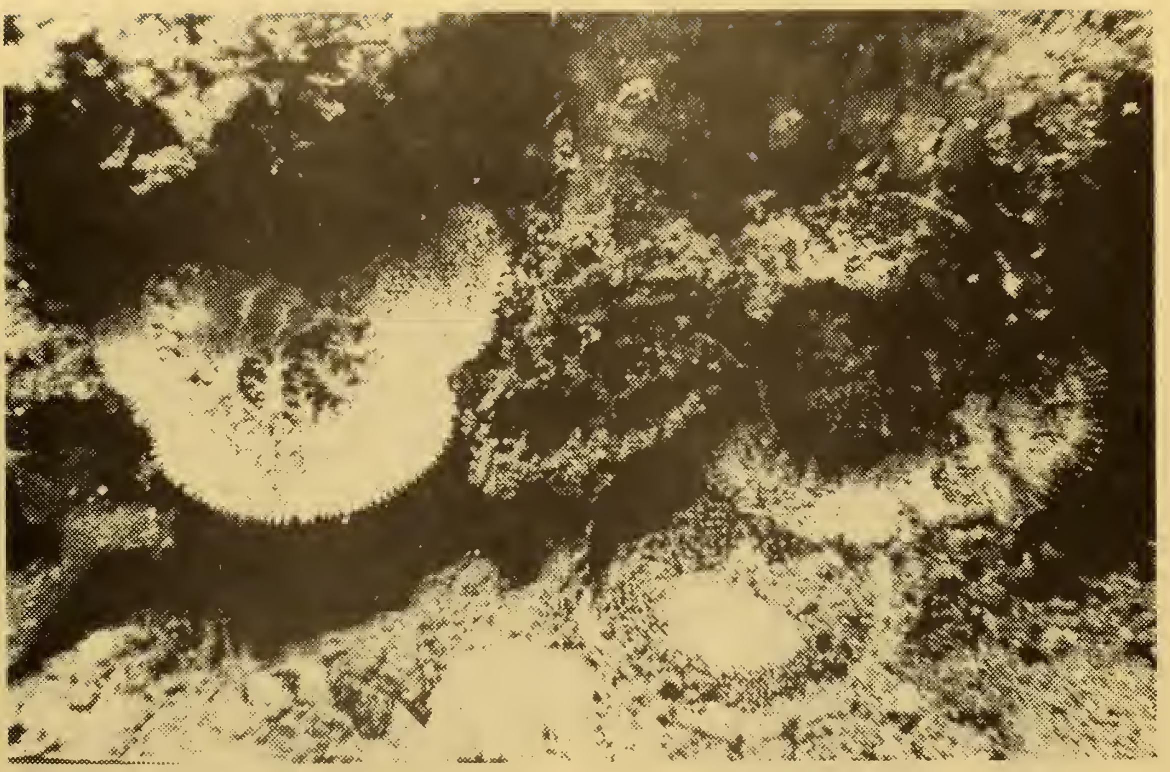

Figure 37. Four Parapholas showing pigmentation variation (x 1 1/2)

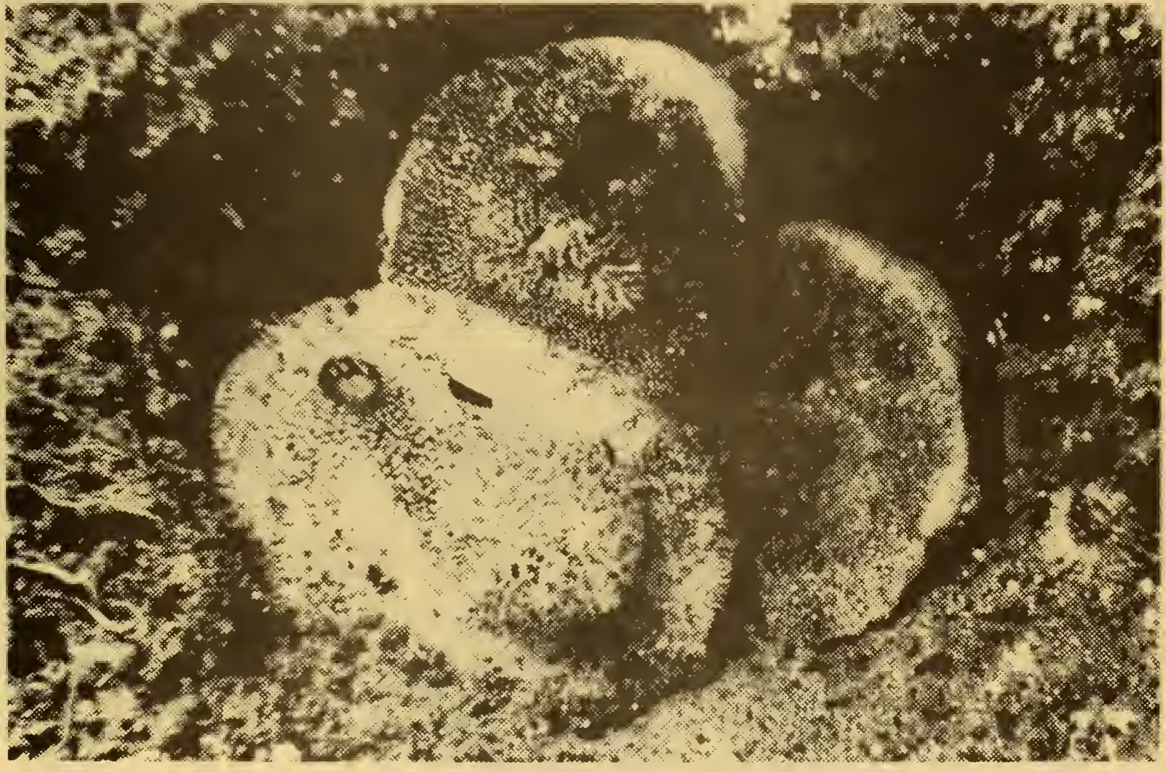

Figure 38. Three Parapholas showing crowding (x 2)

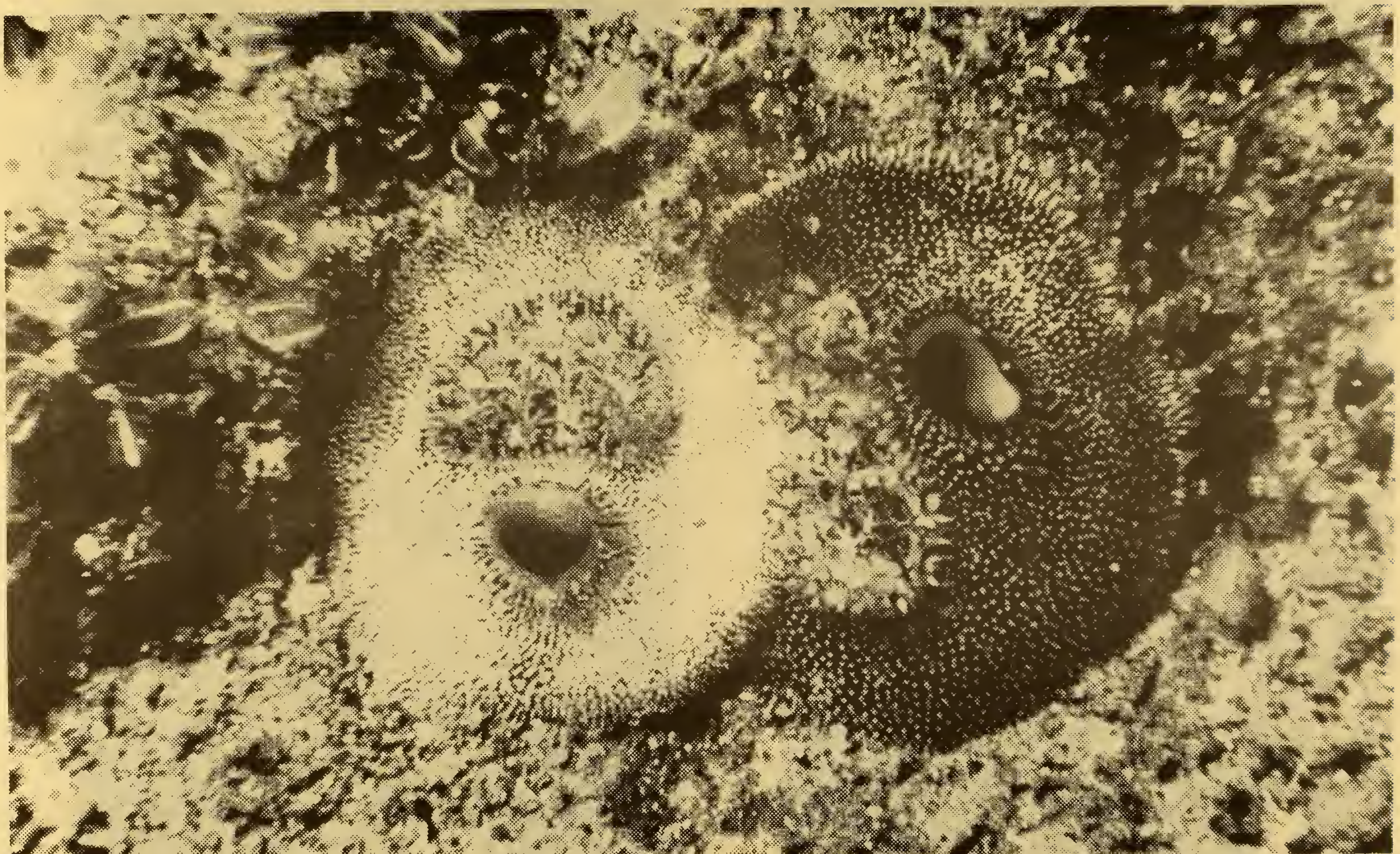

Figure 39. <u>Parapholas</u>, white and red-brown (x 2)

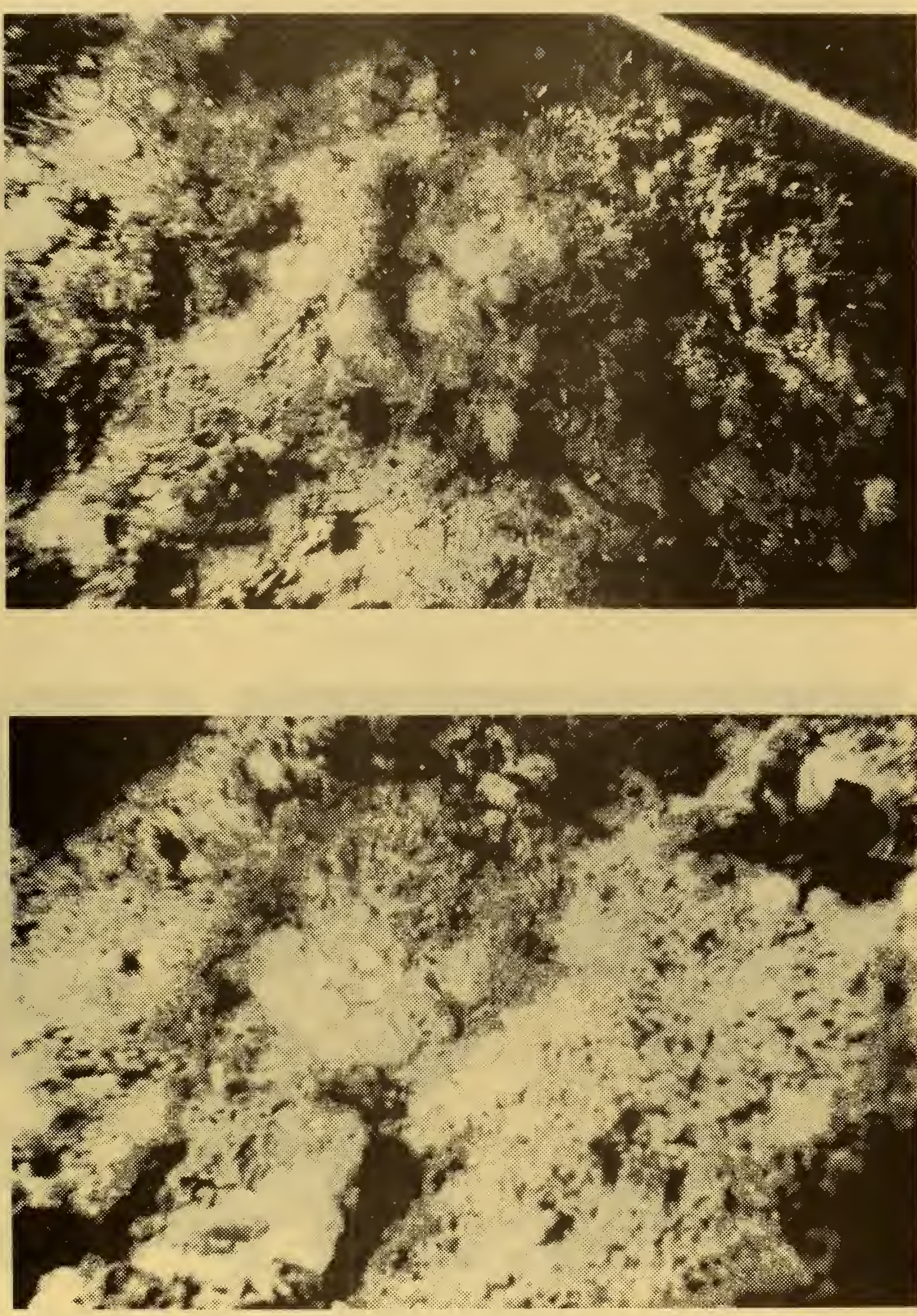

Figure 40. White Parapholas at D-306 (x 1/3)

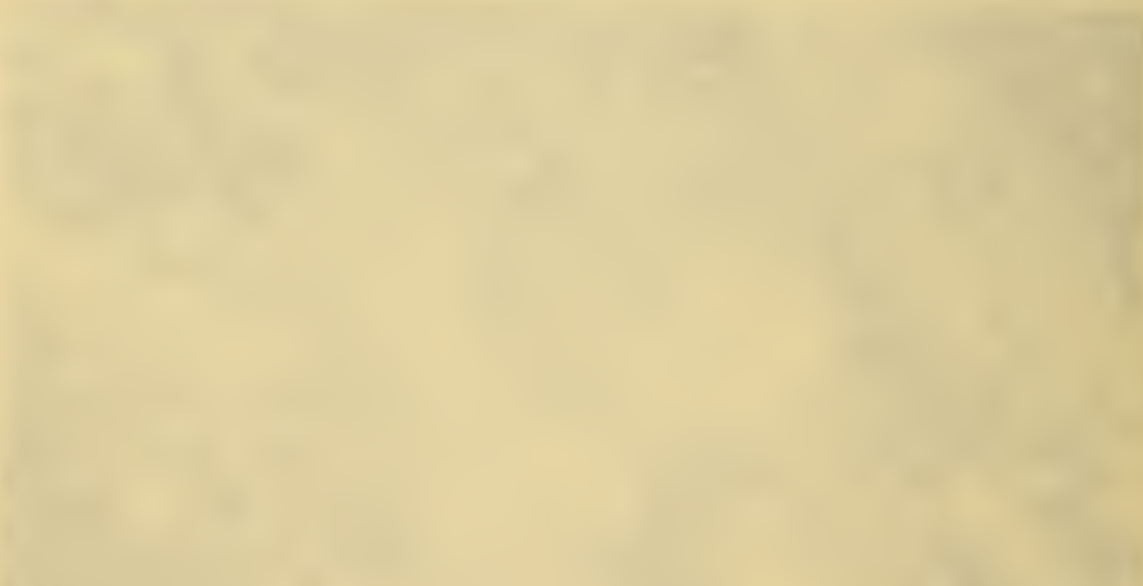

Figure 41. Two Parapholas in sand (x 2)

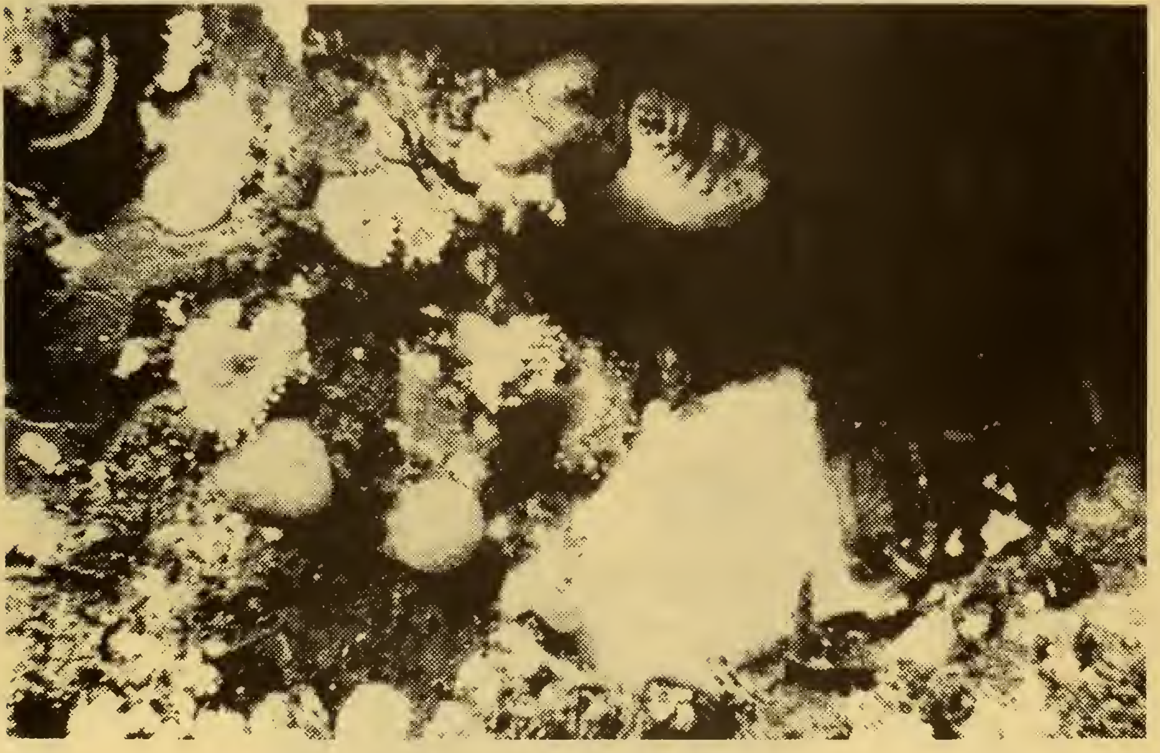

Figure 42. Parapholas (no chimney) protruding from bore (x 1 1/2)

Figure 43. Parapholas showing crowding (x 2)

Figure 44. Four Parapholas showing cylindrical pseudofeces (x 1 1/2)

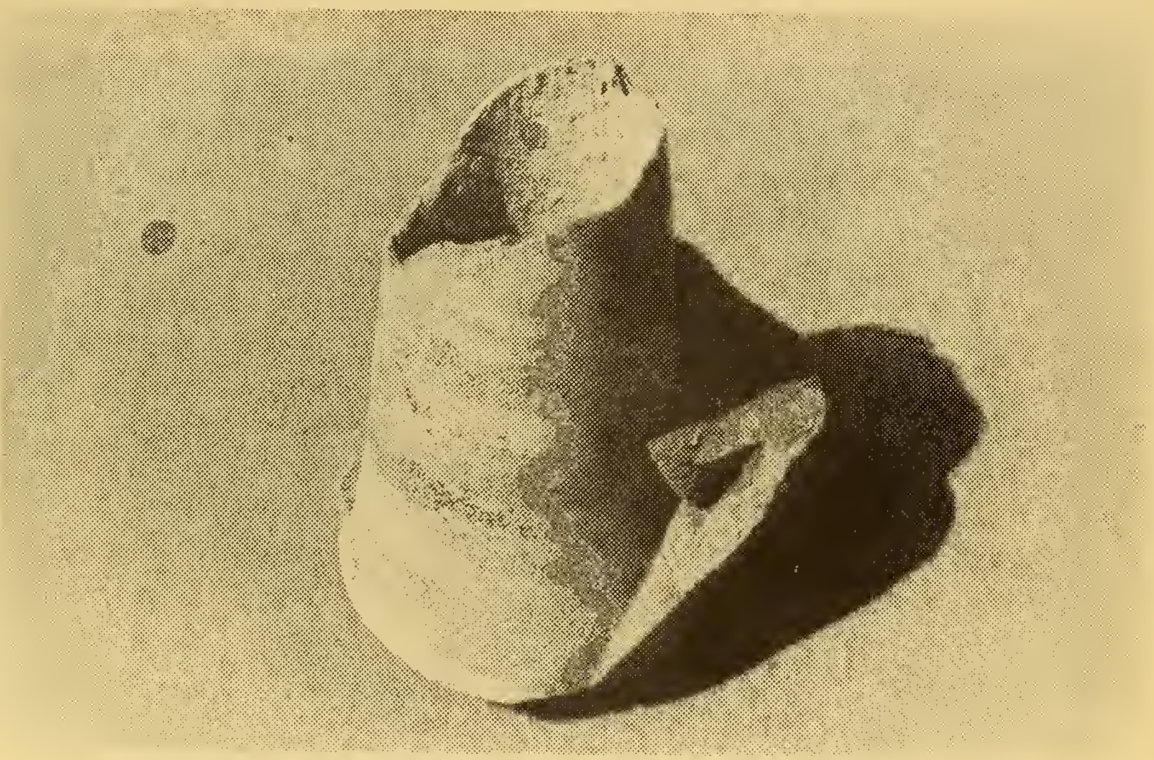

Figure 45. Parapholas chimney (x 1)

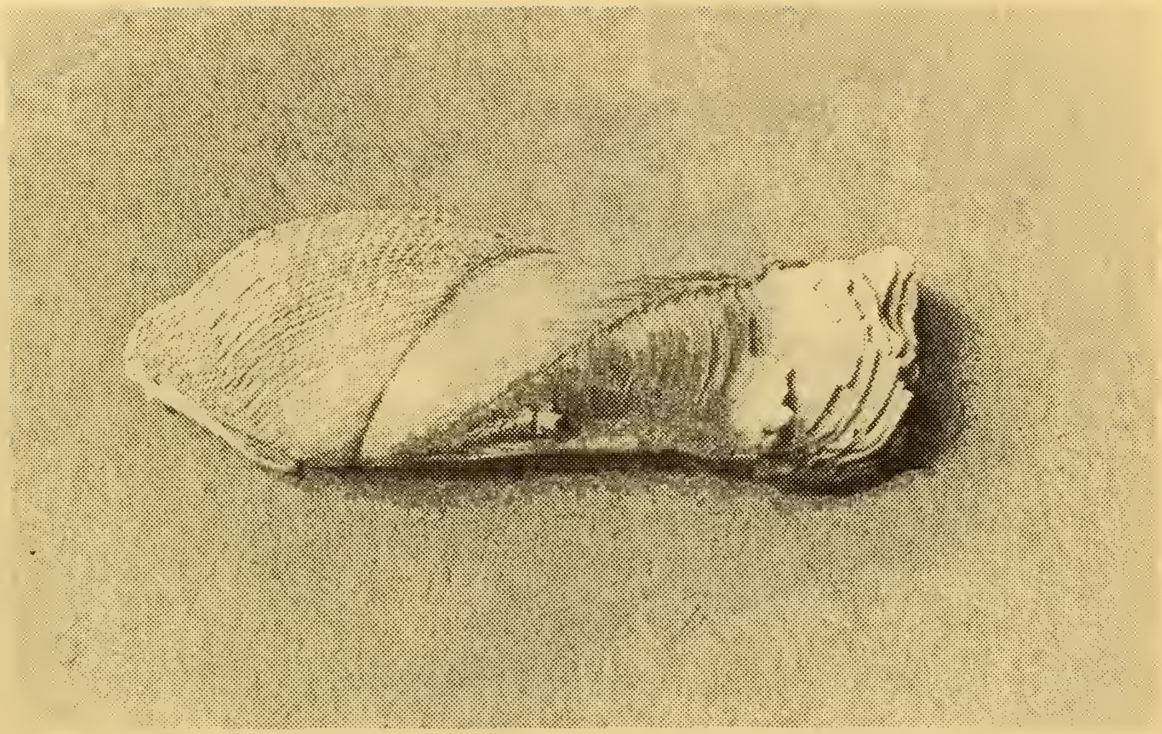

Figure 46. Dorsal view of young Parapholas valve showing chitinous flaps on posterior margin (x 1 1/2)

Figure 47. Ventral view of young Parapholas valve showing pedal gape (x 1 1/2)

Figure 48. Parapholas chimney into which a Lithophaga has bored (x 2/3)

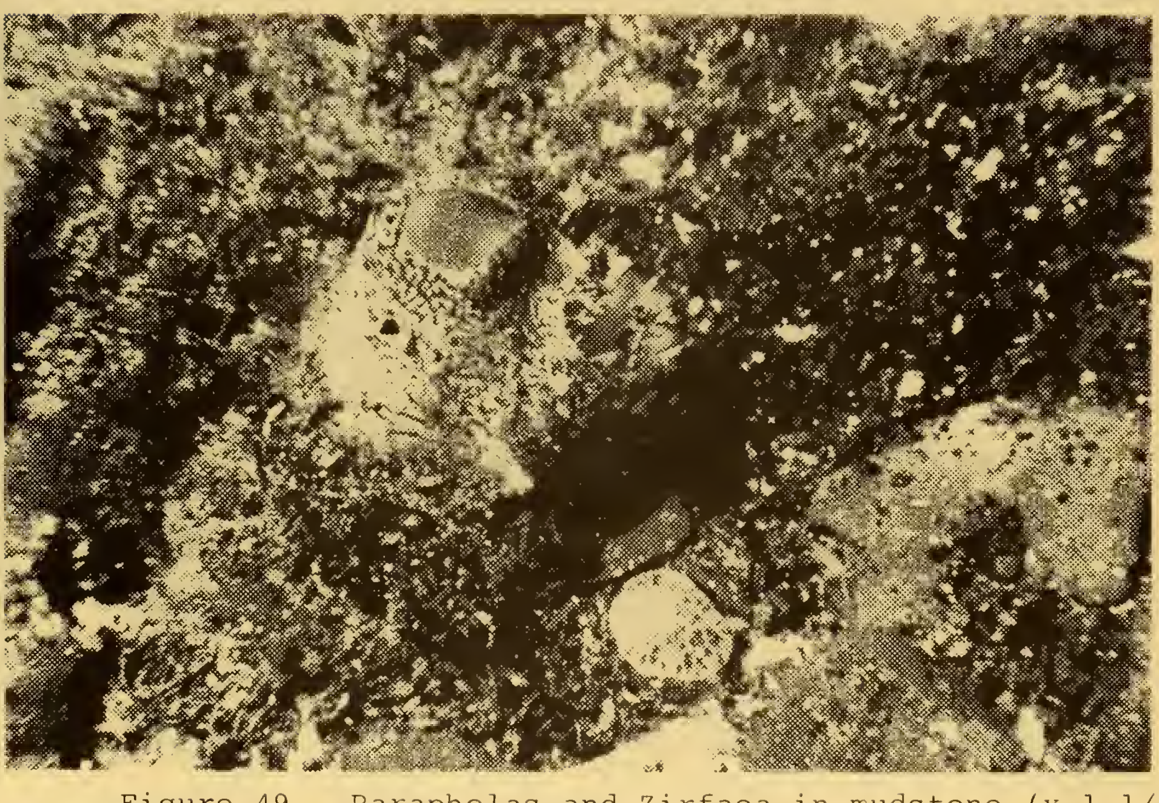

Figure 49. Parapholas and Zirfaea in mudstone (x 1 1/2)

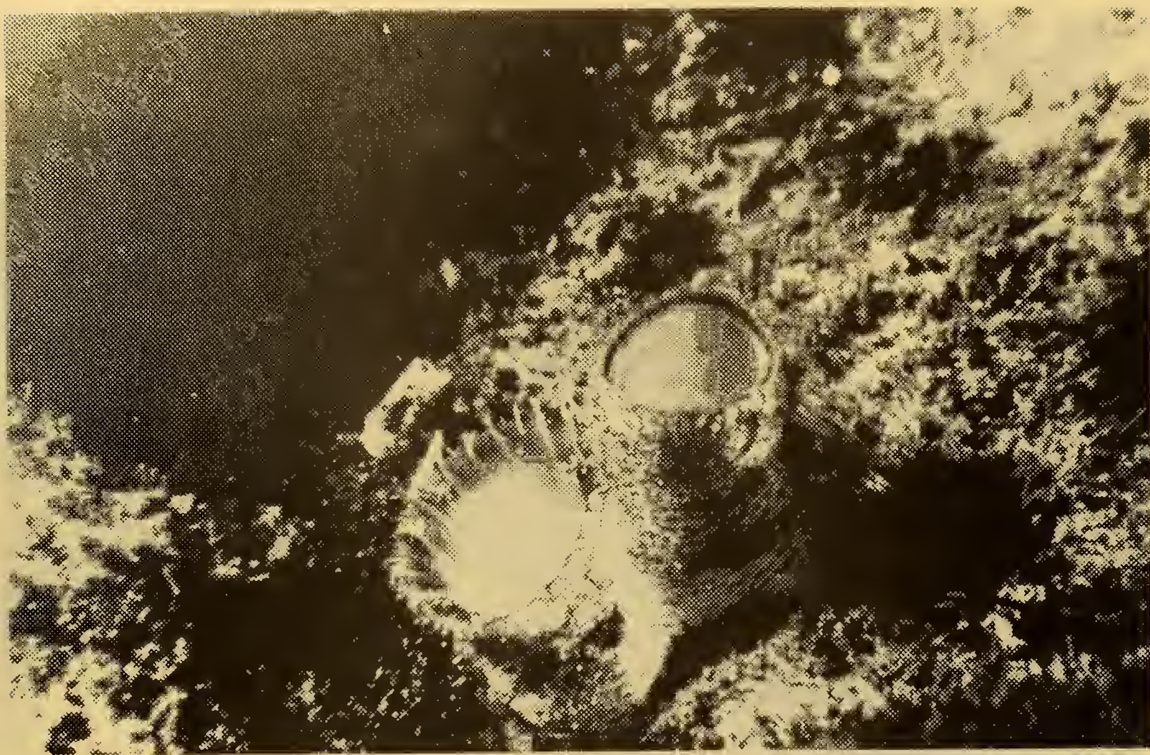

Figure 50. Zirfaea (x 1 1/2)

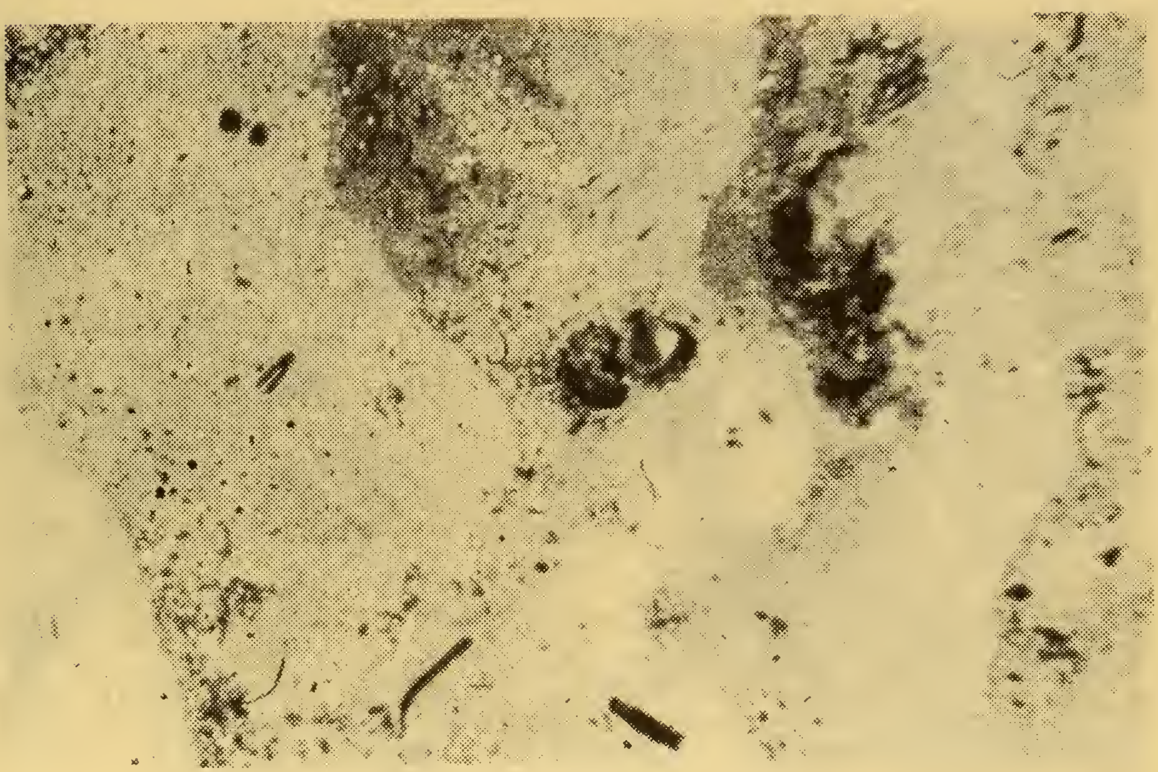

Figure 51. Zirfaea in sand (x 1/3)

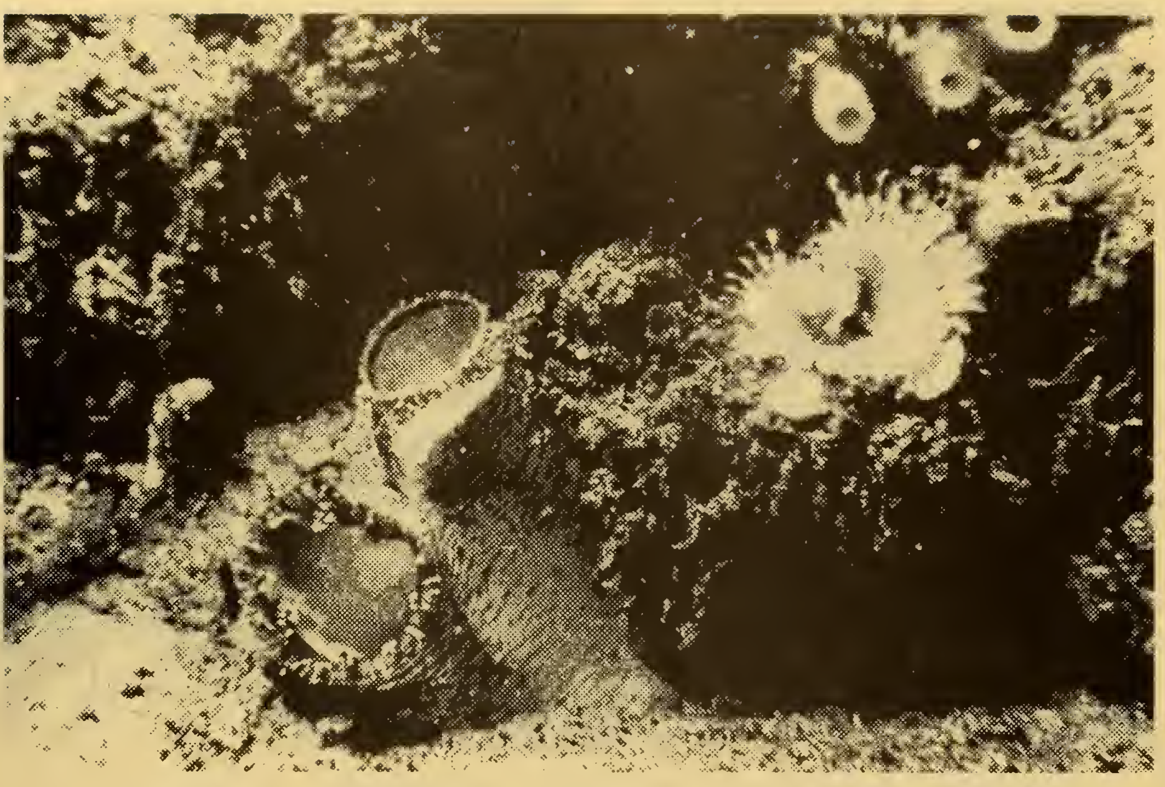

Figure 52. Zirfaea and worm tentacles (x 1 1/2)

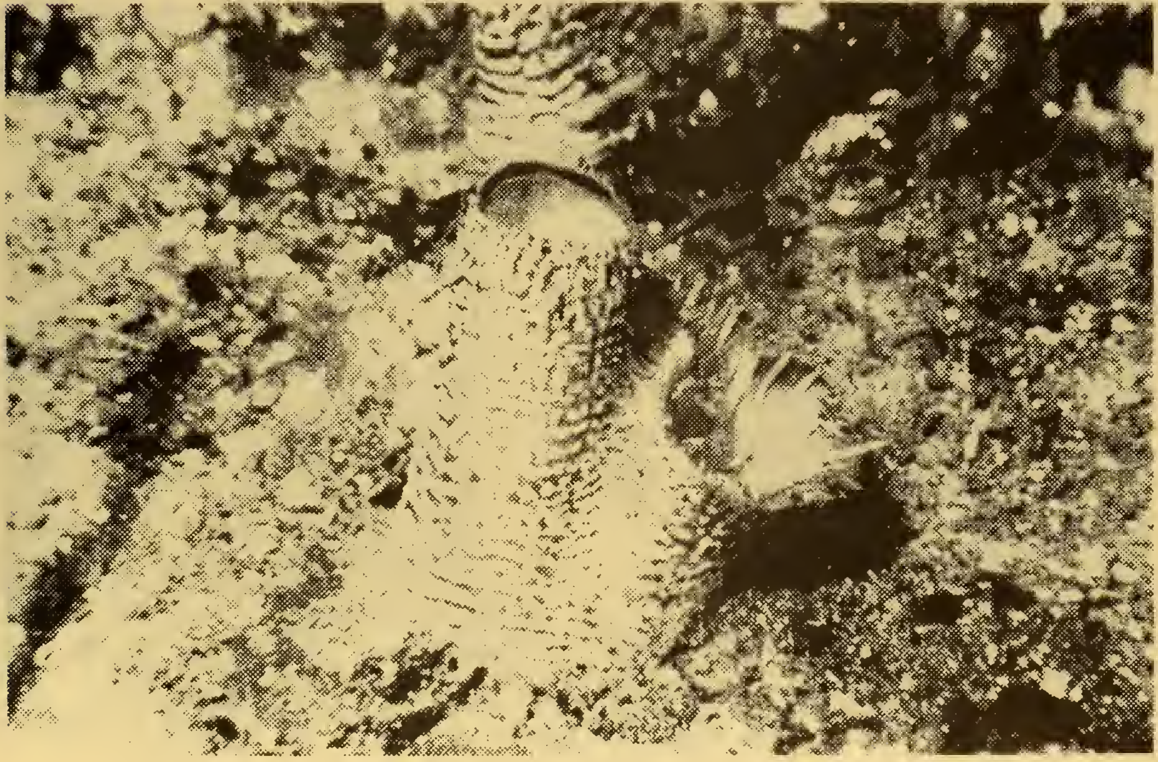

Figure 53. Zirfaea in sand (x 1 1/2)

Figure 54. Zirfaea, horizontal in eroding mudstone (x 1 1/2)

Figure 55. Zirfaea in sand (x 1 1/2)

Figure 56. Two Zirfaea in thin sand (x 1 1/2)

Figure 57. Zirfaea in sand (x 2)

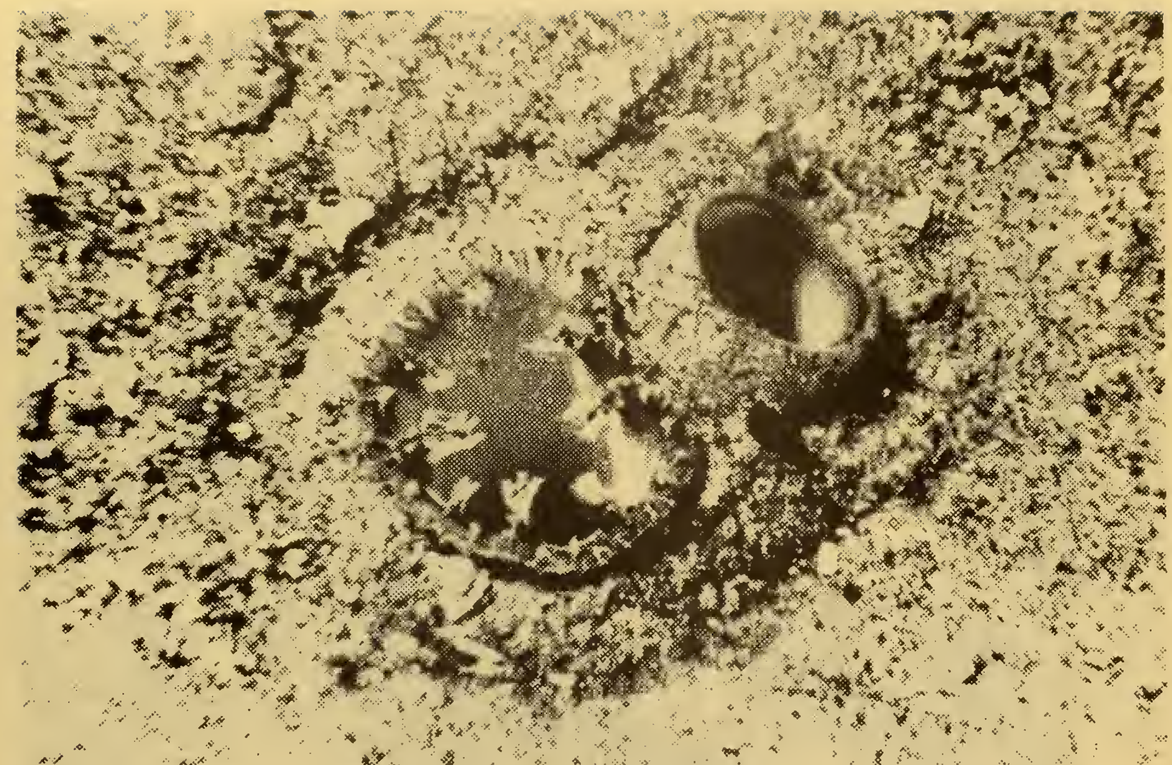

Figure 58. <u>Zirfaea</u> in sand (x 2)

Figure 59. Several <u>Chaceia</u> in eroding bores (x 1/2)

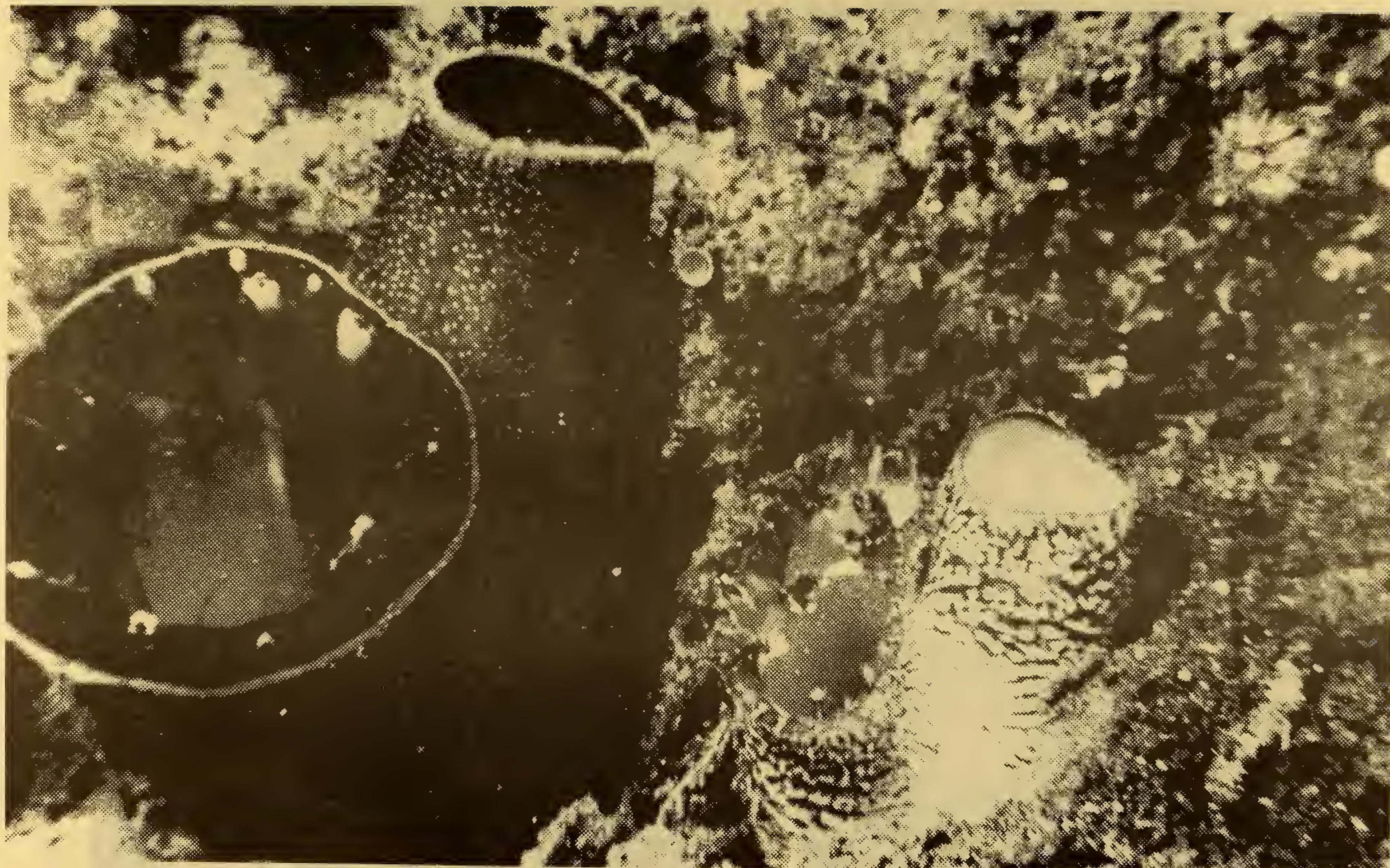

Figure 60. Chaceia and Zirfaea (x 2)

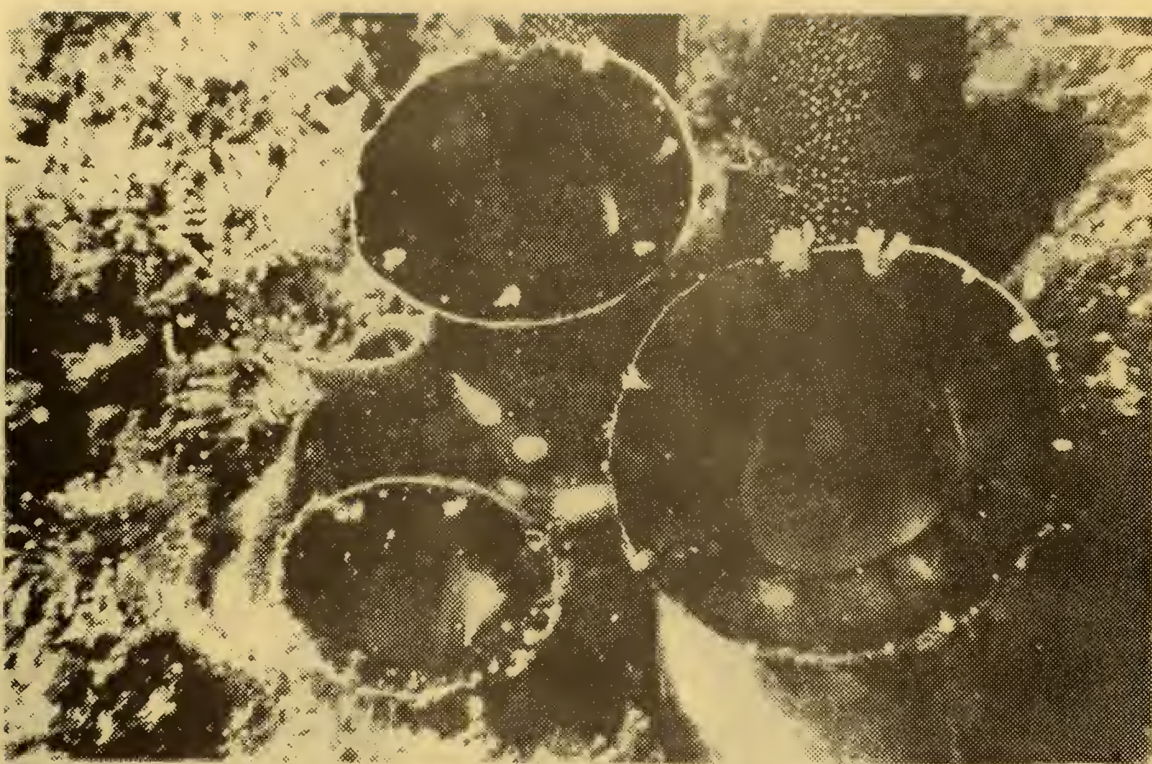

Figure 61. Siphons of 3 Chaceia (x 1 1/2)

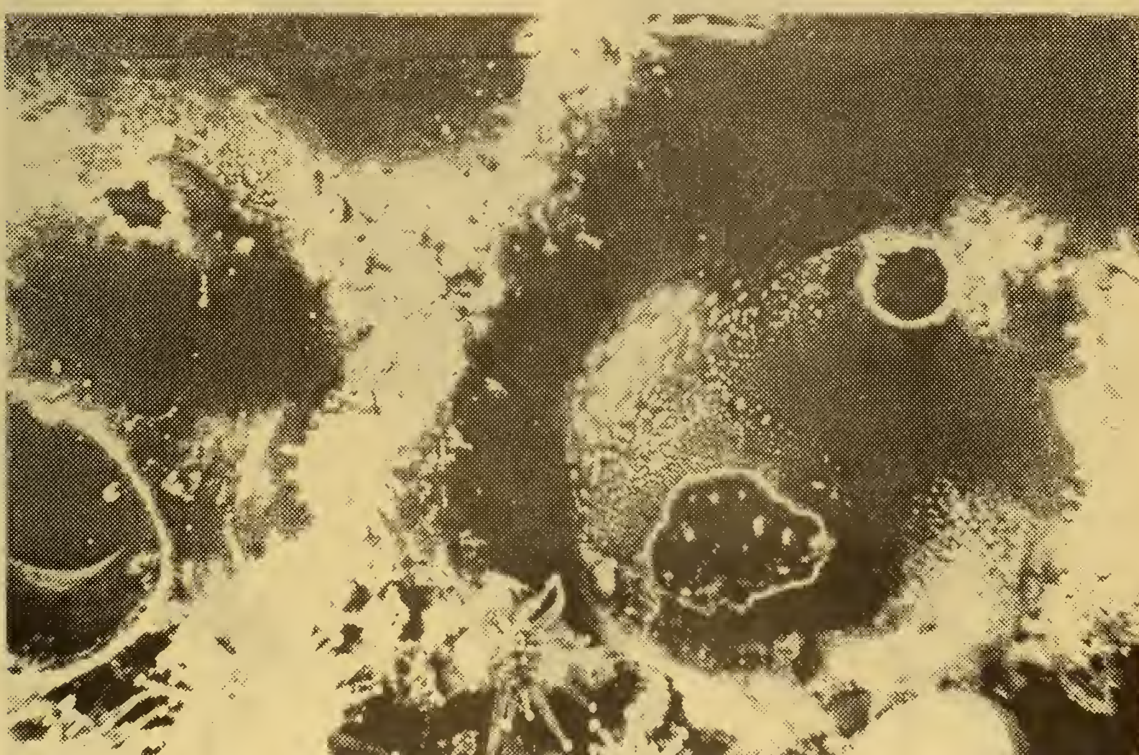

Figure 62. Chaceia in horizontal, eroding bore (x 1 1/2)

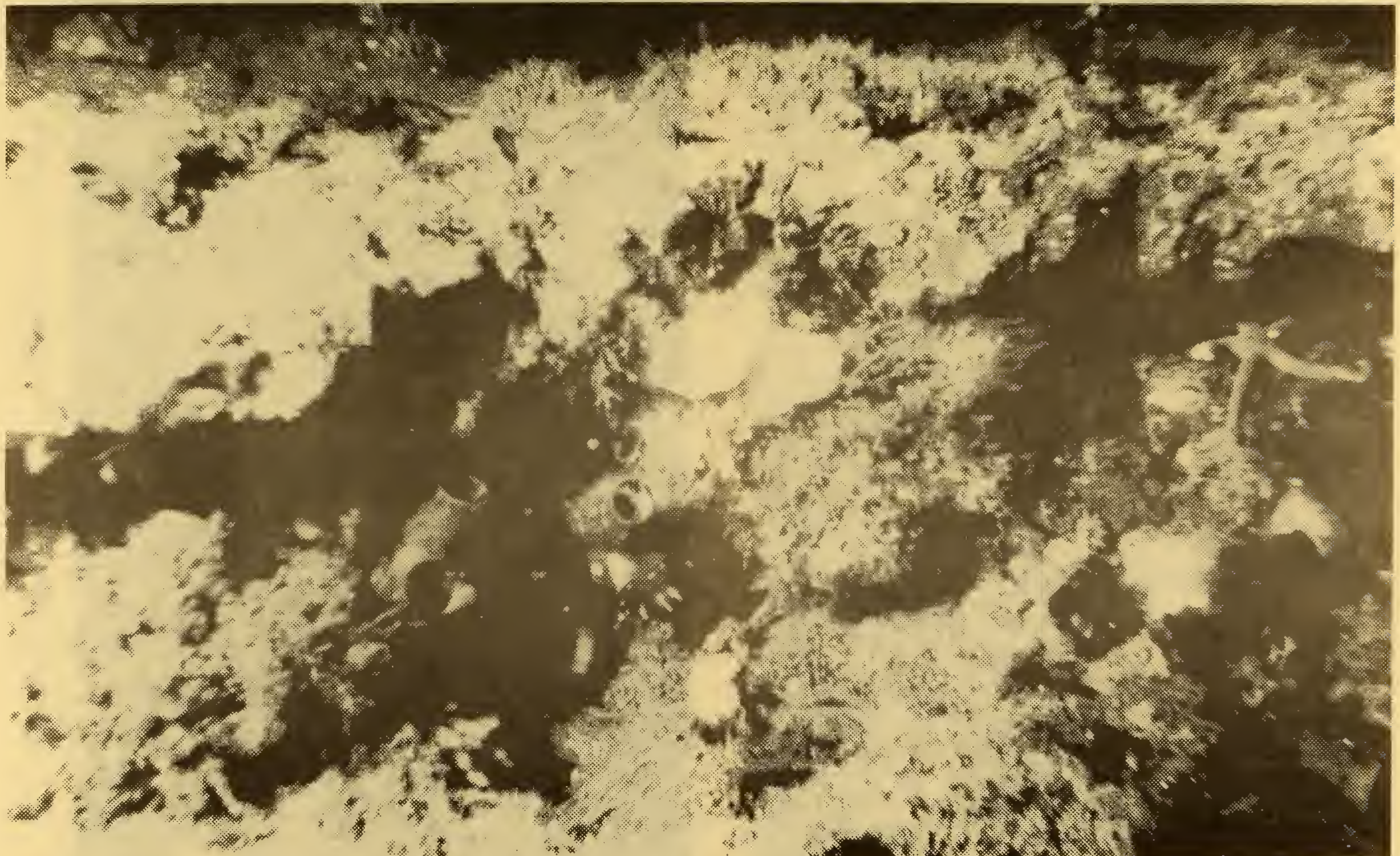

Figure 63. Chaceia boring horizontally under a ledge (x 1/2)

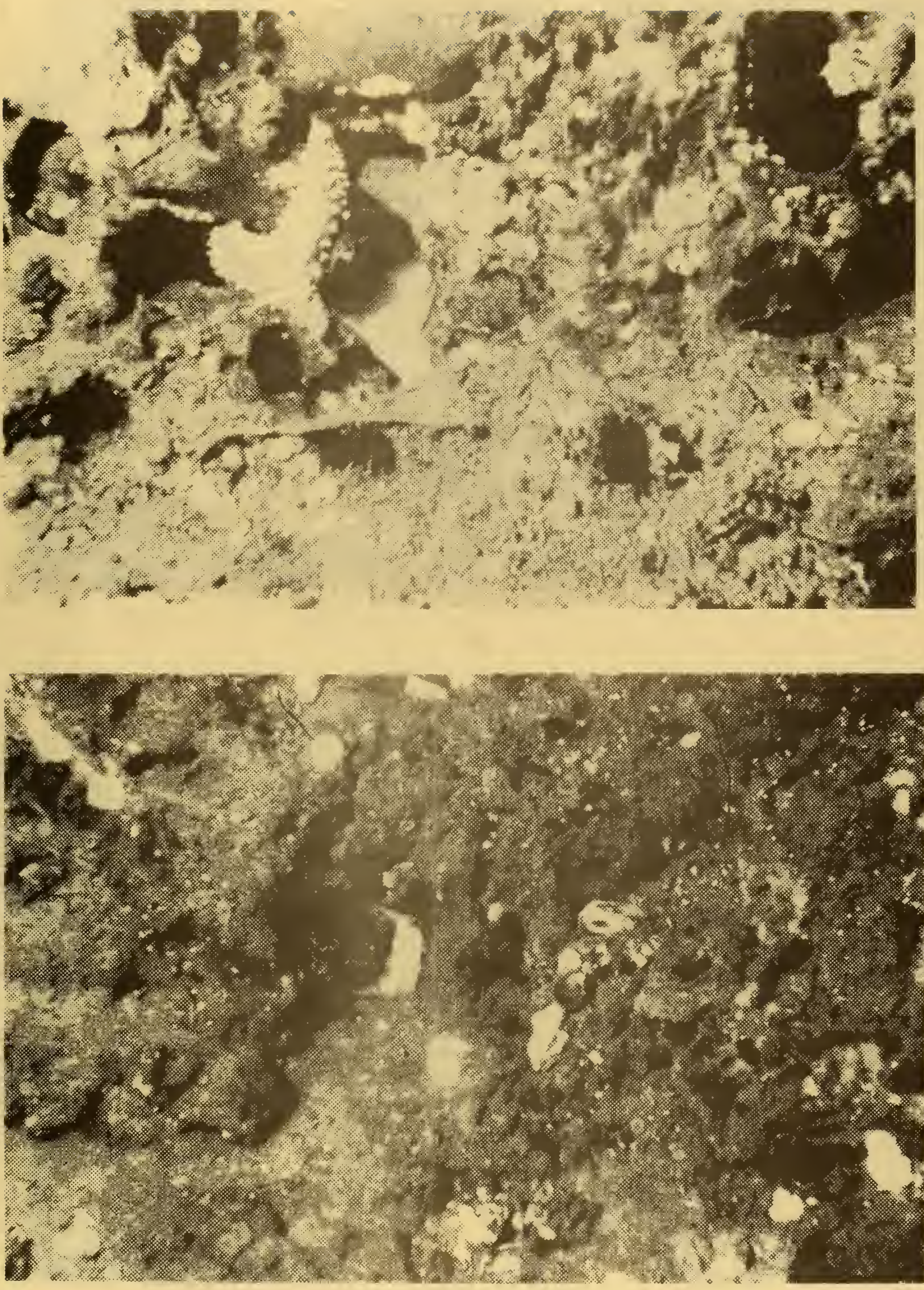

Figure 64. Chaceia protruding from bore (x 1/3)

Figure 65. Chaceia (x 1 1/2)

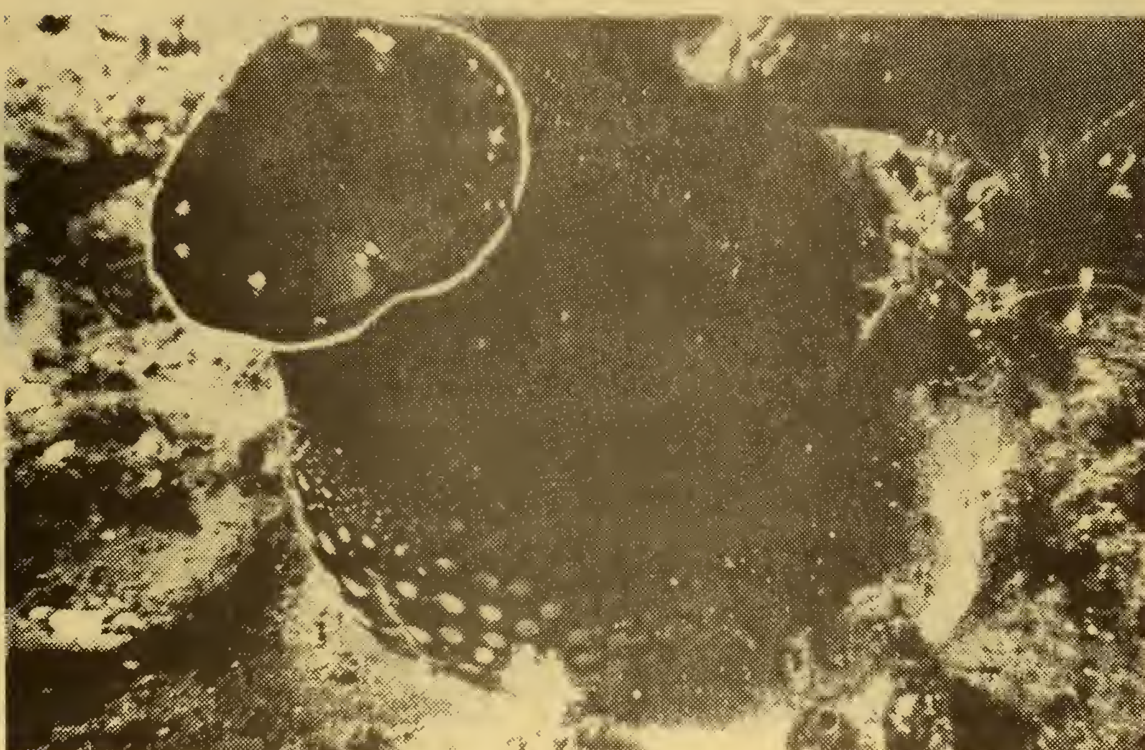

Figure 66. Chaceia Note chitinous spots on siphon exterior (x 1 1/2)

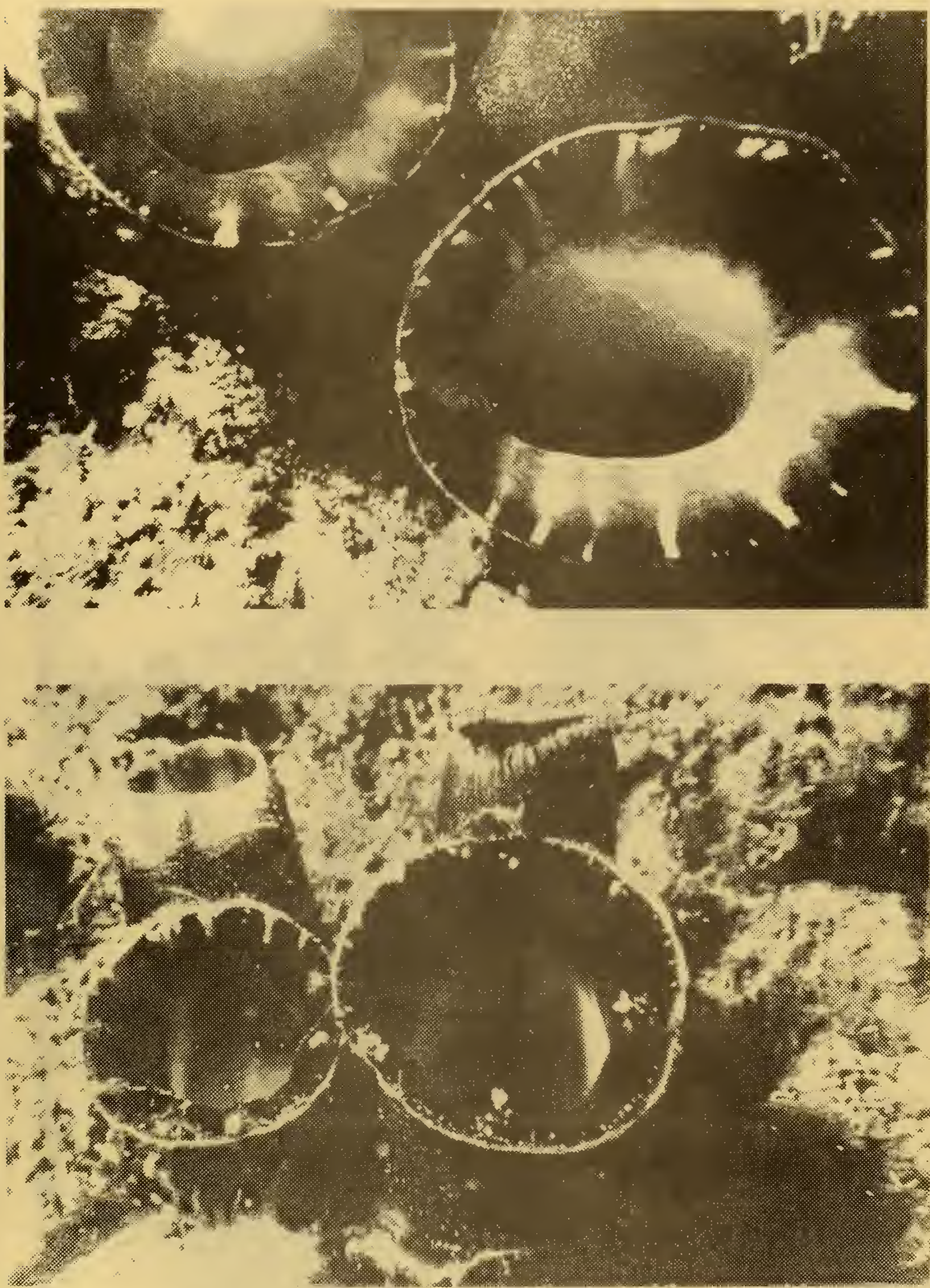

Figure 67. Chaceia (x 1 1/2)

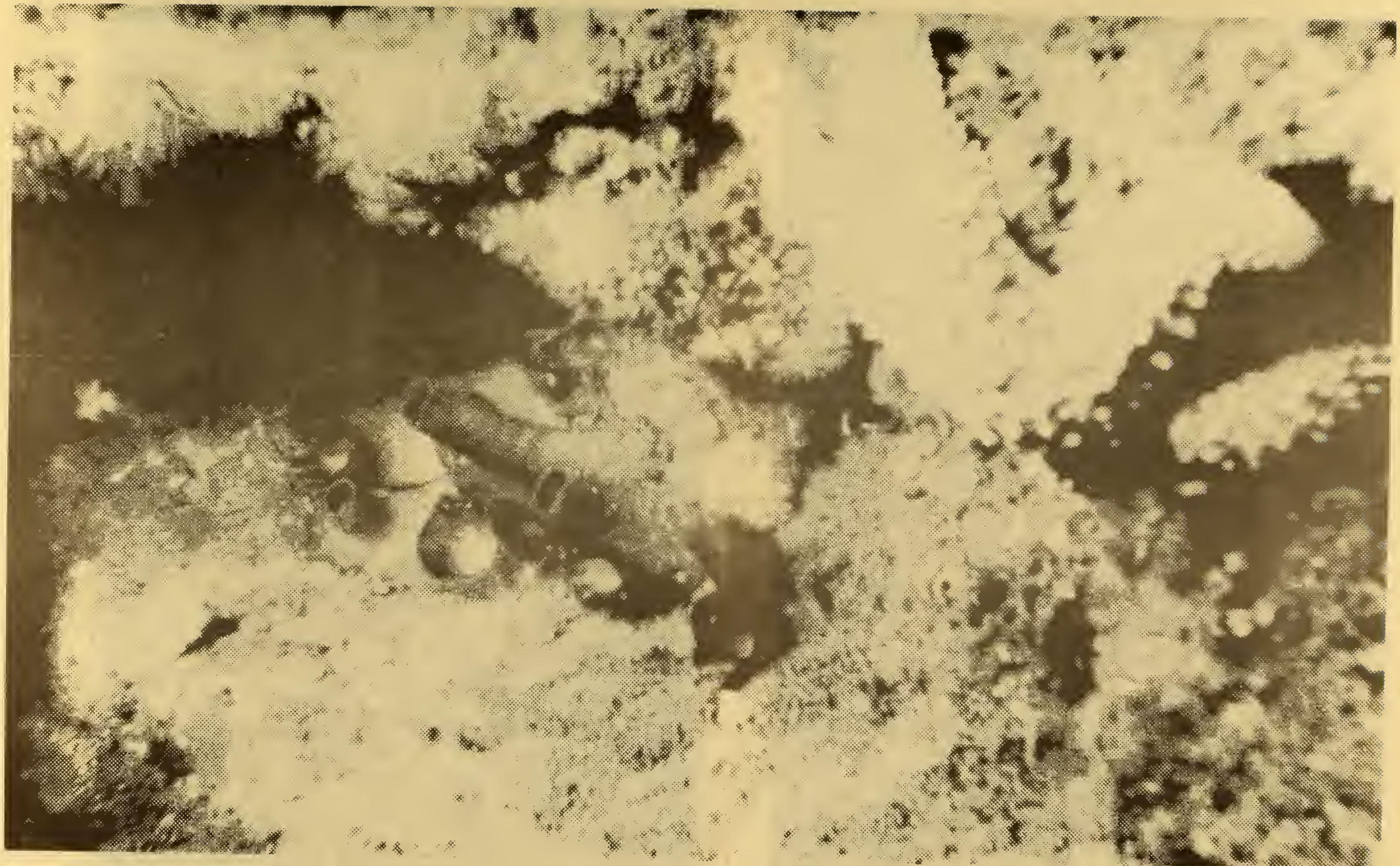

Figure 68. Several <u>Chaceia</u> boring horizontally beneath a layer of hard shale (x 1/3)

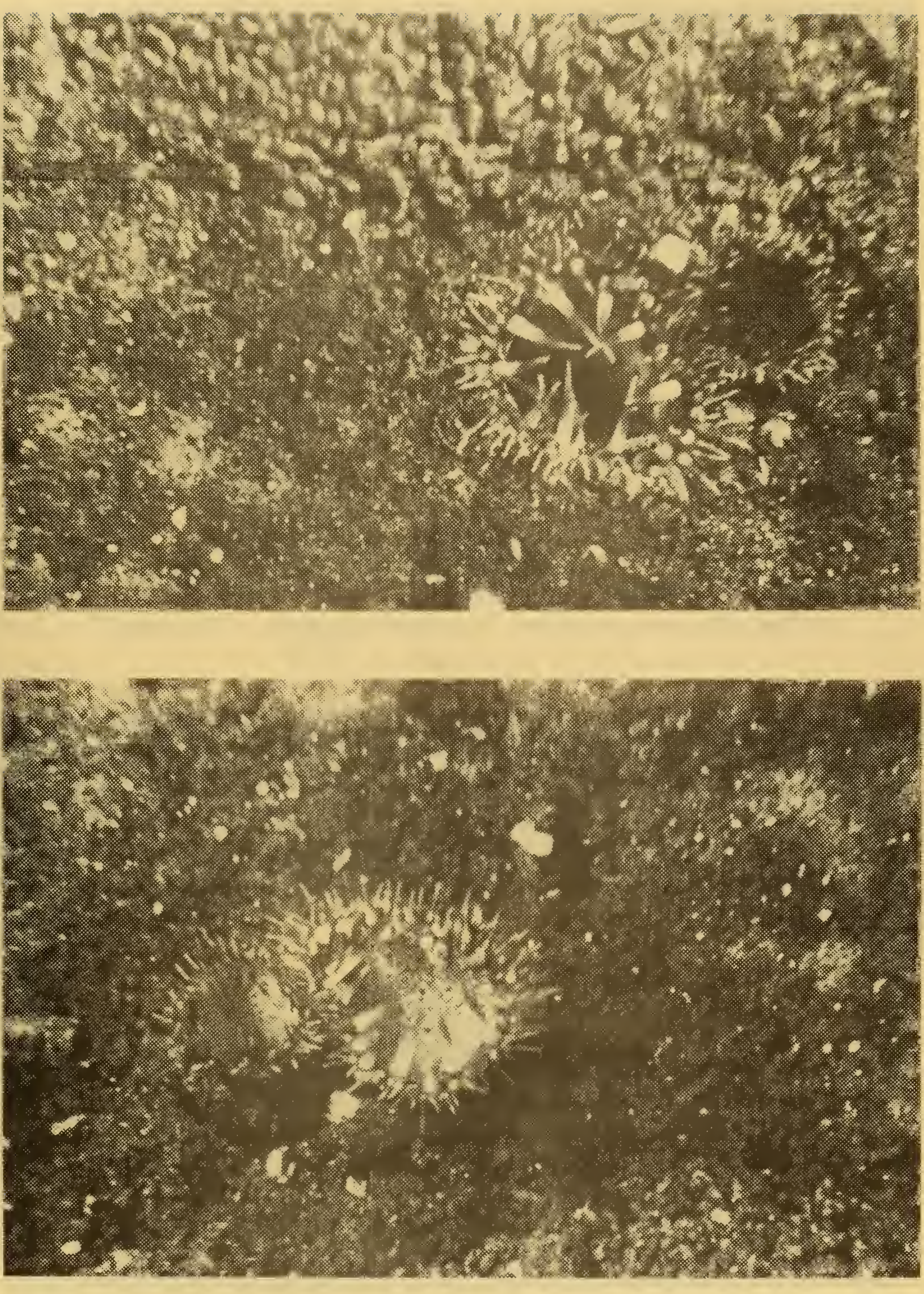

Figure 69. Barnea Note ten unbranched papillae (x 3).

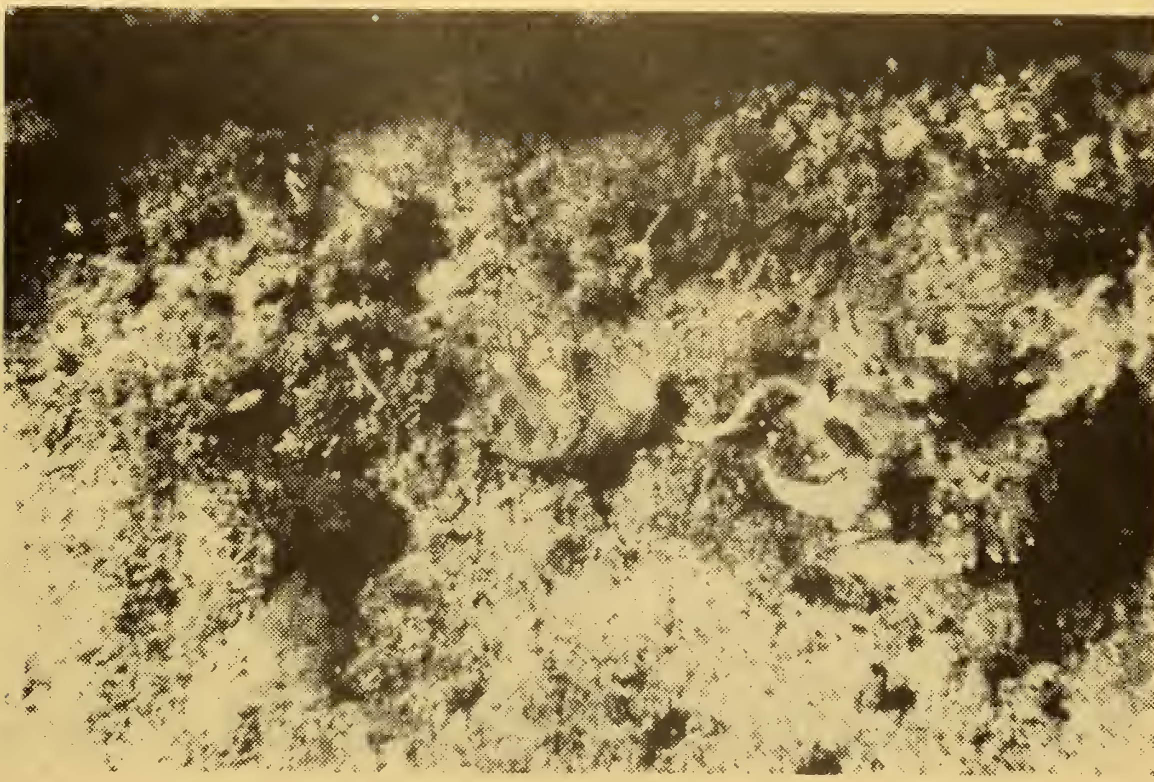

Figure 70. Botula siphons (center and top left) (x 3)

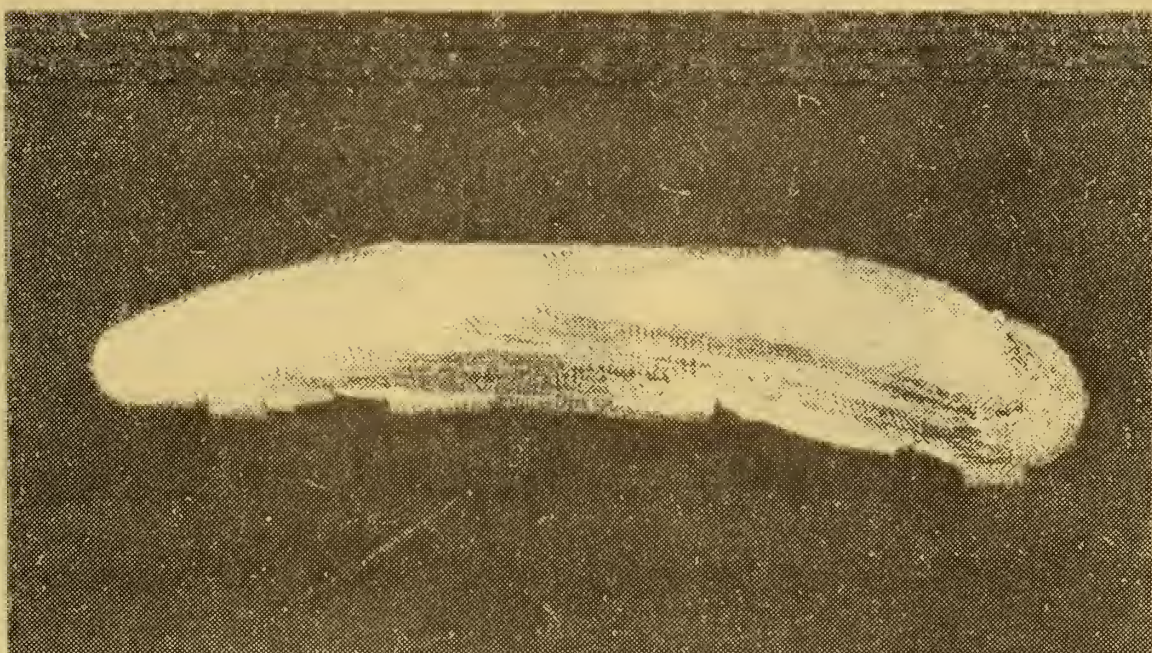

Figure 71. Botula valve with chitinous covering (x 1 1/2)

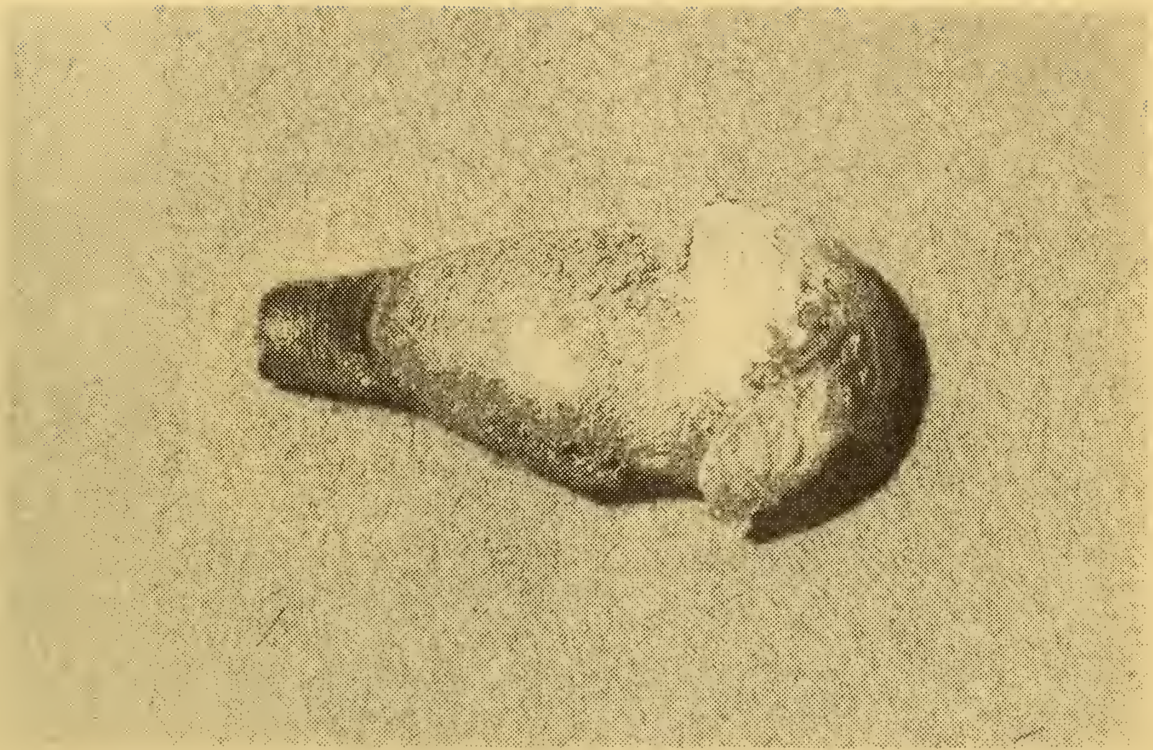

Figure 72. Dorsal view of <u>Penitella conradi</u> valve with siphonoplax and callum (x 3)

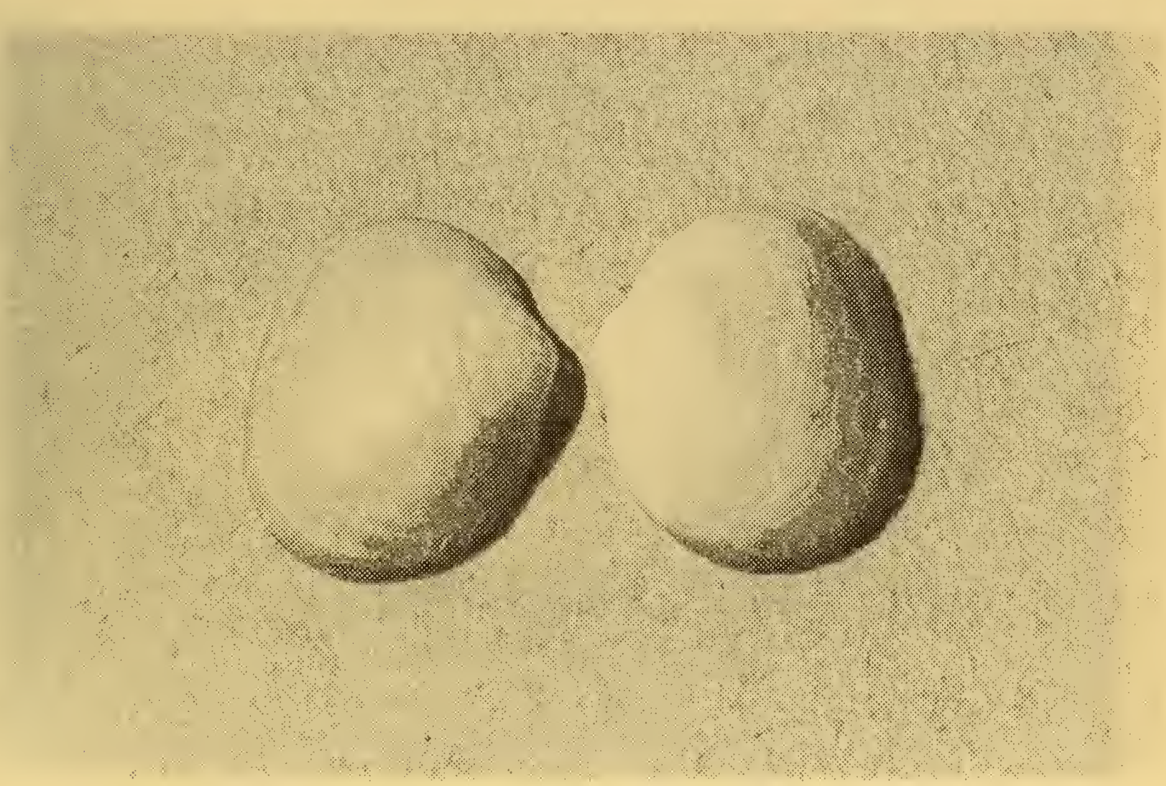

Figure 73. Both valves of <u>Kellia laperousi</u> (x 3)

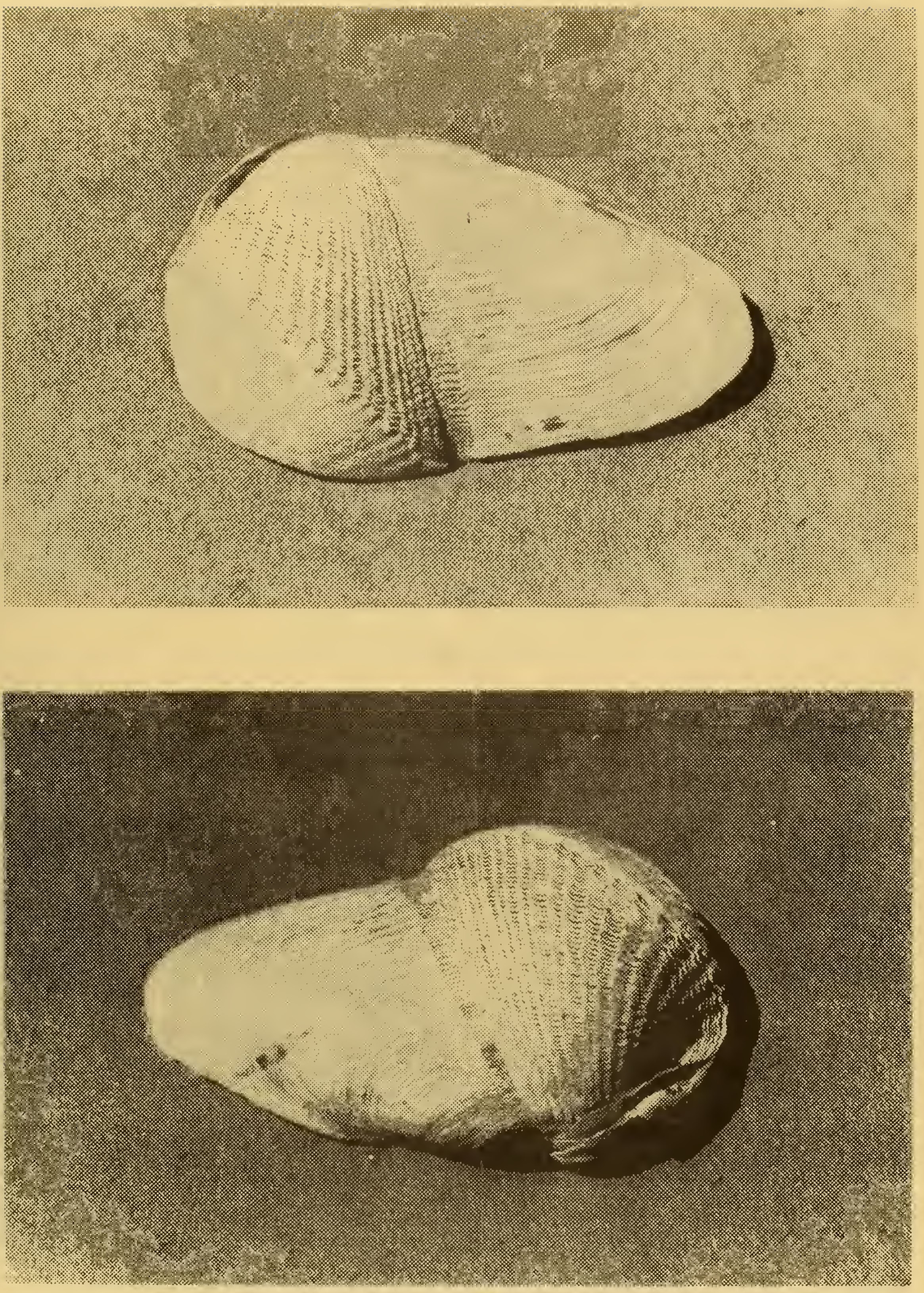

Figure 74. Penitella gabbi valve (x 2)

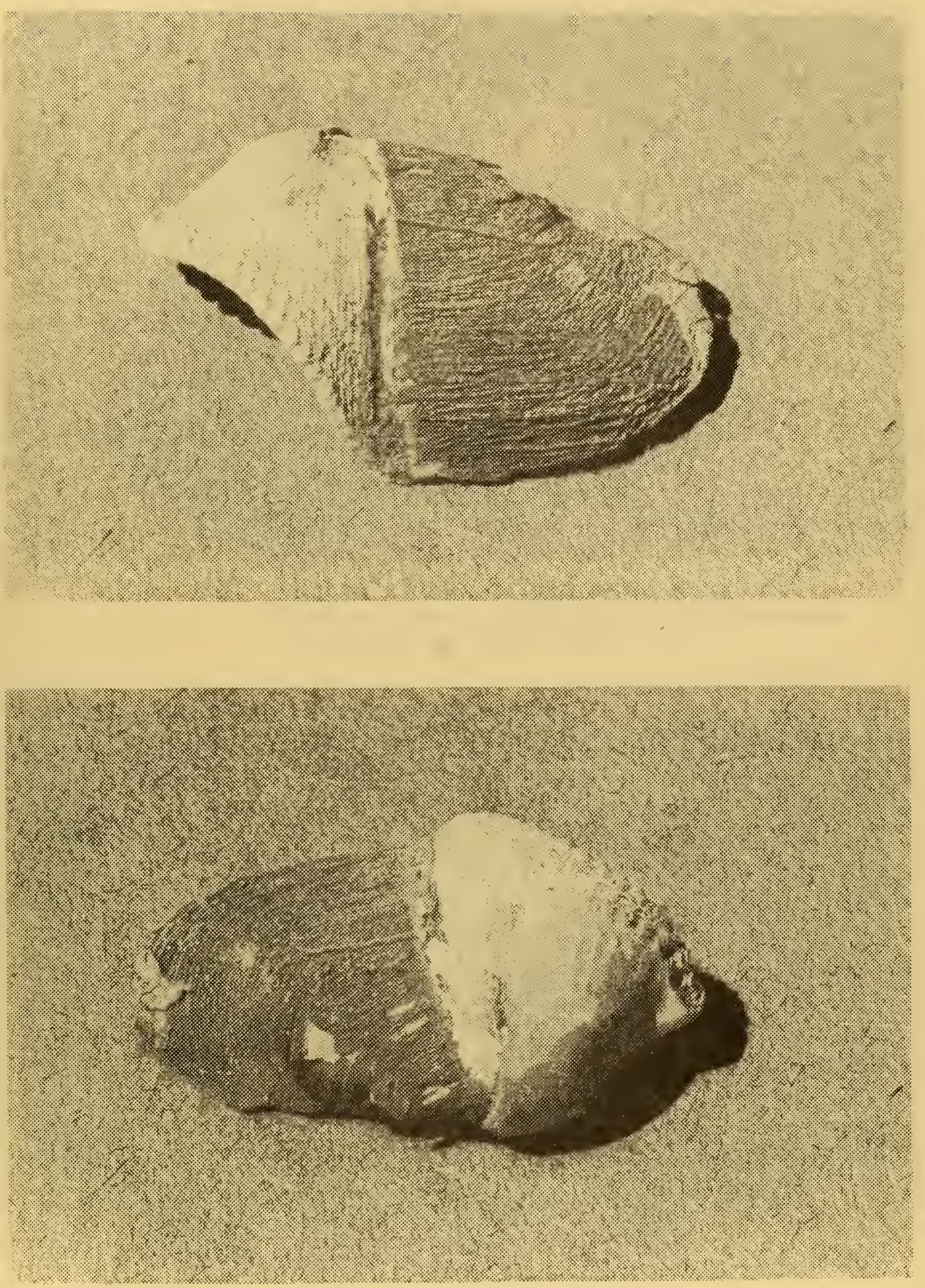

Figure 75. Penitella penita valve (x 3)

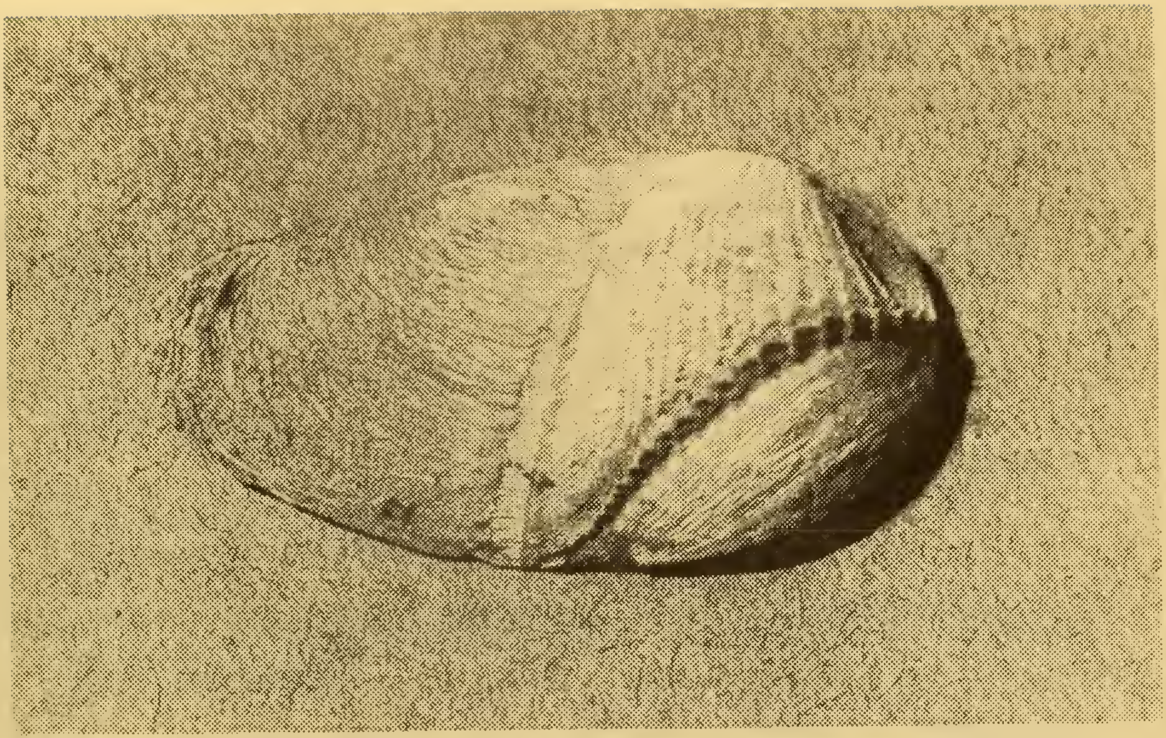

Figure 76. Ventral view of Penitella gabbi valve showing row of thickened imbrications on margin of pedal gape (x 3)

Figure 77. Both valves of Nettastomella (x 3)

BIBLIOGRAPHY

Allen, J.A., "Observations on size composition and breeding of Northumberland populations of Zirphaea crispata (Pholadidae: Bivalvia)," Marine Biology, v. 3, p. 269-275, July 1969.

Church, R., "Underwater Photography: A Mirror in the Sea," Oceans, v. 4, p. 9-32, May-June 1971.

Clapp, W.F. and Kenk, R., Marine Borers: an annotated bibliography, ACR-74, Office of Naval Research, Department of the Navy, 1963.

Cox, K.W., California Abalones, Family Haliotidae, California Department of Fish and Game Fish Bulletin No. 118, 1962.

Evans, J.W. and Fisher, D., "A new Species of Penitella (Family Pholadidae) from Coos Bay, Oregon," The Veliger, v. 8, p. 222-224, 1966a.

Evans, J.W., The Ecology of the Rock-Boring Clam Penitella penita, Ph.D. Thesis, University of Oregon, 1966b.

Evans, J.W., "Relationship between Penitella penita (Conrad, 1837) and Other Organisms of the Rocky Shore," The Veliger, v. 10, p. 148-151, 1967.

Evans, J.W., "The Role of Penitella penita (Conrad 1837) (Family Pholadidae) as Eroders Along the Pacific Coast of North America," Ecology, v. 49, p. 156-159, 1968a.

Evans, J.W., "Growth Rate of the Rock-Boring Clam Penitella penita (Conrad 1837) in Relation to Hardness of Rock and Other Factors," Ecology, v. 49, p. 619-628, 1968b.

Fitch, J.E., Common Marine Bivalves of California, California Department of Fish and Game Fish Bulletin No. 90, 1953.

Greene, H.G., Geology of Southern Monterey Bay and its Relationship to the Ground Water Basin and Salt Water Intrusion, United States Department of the Interior, Geological Survey, p. 8-45, 1970.

Haderlie, E.C., "Marine Fouling and Boring Organisms in Monterey Harbour," The Veliger, v. 10, p. 327, 1968.

Haderlie, E.C., "Marine Fouling and Boring Organisms in Monterey Harbour--Second Year of Investigation," The Veliger, v. 12, p. 182-192, 1969.

Haderlie, E.C., "Fouling Organisms in the Harbour at Monterey, California," in Proceedings of the Second International Congress of Marine Corrosion and Fouling, Athens, p. 1-14, 1970.

Haderlie, E.C., "Ecological Implications of Breakwater Construction in Monterey Harbour," Marine Pollution Journal, v. 2, p. 90-92, June 1971.

Jaccarini, V. and Bannister, W.H., "The Pallial Gland and Rock Boring in Lithophaga l.,"Journal of Zoology, v. 154, p. 397-401, 1968.

Johnson, M.E. and Snook, H.J., Seashore Animals of the Pacific Coast, Macmillan Company, 1927.

Keen, A.M., Marine Molluscan Genera of Western North America, Stanford University Press, 1963.

Light, S.F., and others, Intertidal Invertebrates of the Central California Coast, University of California Press, 1954.

Minter, C.S.,III, Sublittoral Ecology of the Kelp Beds off Del Monte Beach, Monterey, California, M.S. Thesis, Naval Postgraduate School, 1971.

Nair, N.B. and Ansell, A.D., "The Mechanism of Boring in Zirphaea crispata (L.)," Proceedings of the Royal Society of London,Series B, v. 170, p. 155-173, 1968.

Trumbauer, D.S., A Coliform Bacteria Survey of Monterey Bay off Del Monte Beach, M.S. Thesis, Naval Postgraduate School, 1966.

Turner, R.D., "The Family Pholadidae in the Western Atlantic and the Eastern Pacific Part I--Pholadinae," Johnsonia, v. 3, p. 1-64, 17 May 1954.

Turner, R.D., "The Family Pholadidae in the Western Atlantic and the Eastern Pacific Part II--Martesiinae, Jouannetiinae and Xylophaginae,"Johnsonia, v. 3, p. 65-160, 29 March 1955.

Yonge, C.M., "Marine Boring Organisms," Research, v. 4, p. 162-167, April 1951.

Yonge, C.M., "On the Primitive Significance of the Byssus in the Bivalvia and its Effects in Evolution," Journal of the Marine Biology Association of the United Kingdom, v. 42, p. 113-125,1962.

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13. ABSTRACT

Divers using SCUBA gear gathered and identified rock-boring pelecypods found in the subtidal outcrops of Monterey silicious shale off Del Monte Beach, Monterey, California. Underwater photographs were taken of all the recognizable species present.

A species distribution and mapping survey was made along two transects, one of which would be subjected to radical ecological change after isolation from the open sea by a proposed breakwater project.

Most species found are common to both transects. Their distribution is variable and depends to a great extent on the character of the substrate, which varies from soft, carbonate-rich mudstone to chert. However, within this framework of distribution dependent on substrate, there are inconsistencies which remain unresolved.

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